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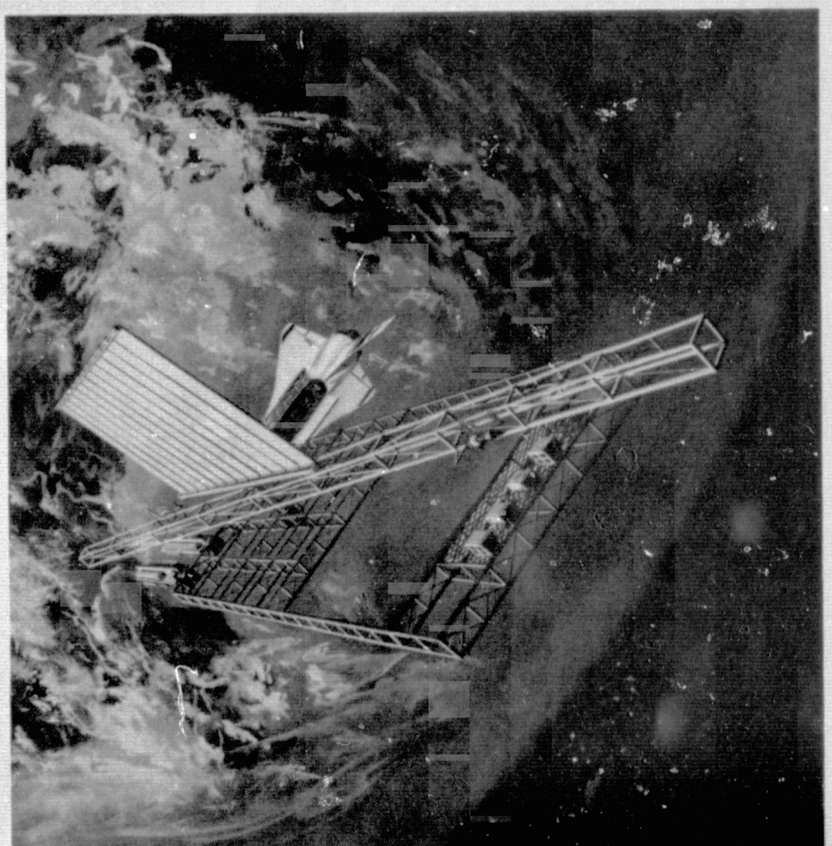
CR 151352

ORBITAL CONSTRUCTION DEMONSTRATION STUDY

FINAL REPORT

(CONTRACT NAS 9-14916)



(NASA-CR-151352) ORBITAL CONSTRUCTION DEMONSTRATION STUDY Final Report (Grumman Aerospace Corp.) 78 p HC A05/MF A01 CSCL 22A
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ORBITAL CONSTRUCTION DEMONSTRATION STUDY

FINAL REPORT

(CONTRACT NAS 9-14916)

Prepared for

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas 77058

by

Grumman Aerospace Corporation
Bethpage, New York 11714

REPORT No. NSS-OC-RP-008

1 DECEMBER 1976

CONTENTS

CONTENTS (Cont'd)

ILLUSTRATIONS

ILLUSTRATIONS (Cont'd)

ILLUSTRATIONS (Cont'd)

Section 1

INTRODUCTION & SUMMARY

The exploration and utilization of space has witnessed a continuous growth in spacecraft size and weight. Many applications are now envisioned which require ultra-large space structures for implementation. The Space Transportation System (STS) is capable of putting large masses into orbit, but these future spacecraft geometries are not compatible with the launch vehicle payload bay size. It is clear that an orbital construction system will be required if we are to have ultra-large structures in space.

Conceptual studies and preliminary designs have been conducted in recent years to define potential mission requirements, structural concepts, and operations for spacecraft utilizing ultra-large structures. As a result, sufficient information exists to define a development program for demonstrating and evaluating orbital construction techniques needed to implement these ambitious programs. The initial phase of this study identified construction technologies needing orbital demonstration and defined demonstration articles that would solve these problems.

The key outputs of this study are conceptual design and program plan for an Orbital Construction Demonstration Article (OCDA), Figure 1-1, that can be used for evaluating and establishing practical large structural assembly operations. A flight plan for initial placement and continued utility is presented as a basis for an entirely new Shuttle payload line-item having great future potential benefit for space applications. If the construction cencepts proven during the program initiated in this study result in assembly of power generating plants in orbit, or other similar expansion of man's usage of space, the return to the nation would be enormous.

The OCDA would be a three-axis stabilized platform in low-earth orbit with many structural nodals for mounting large construction and fabrication equipments. These equipments would be used to explore methods for constructing the large structures for future missions. Actual creation of the OCDA in orbit would provide valuable experience toward this goal. The OCDA would be supported at regular intervals by the Shuttle. Construction experiments and consumables resupply are performed during Shuttle visit periods. A 250 kw solar array provides sufficient power to support the Shuttle while attached to the OCDA and to run ambitious construction experiments at the same time. Wide band communications with a Telemetry and Data Relay Satellite (TDRS) compatible high gain antenna can be used between Shuttle revisits to perform remote controlled, TV assisted construction experiments.

The study guidelines and major assumptions used in performing the analyses are:

- The system must be Shuttle compatible
- Initial OCDA placement must utilize two to six Shuttle flights
- Assume a 1981 technology base
- IOC 1984

In addition to these groundrules, it was also felt that the OCDA should constitute a logical programmatic step between the capability afforded by individual Shuttle missions and the capabilities of a permanent manned facility.

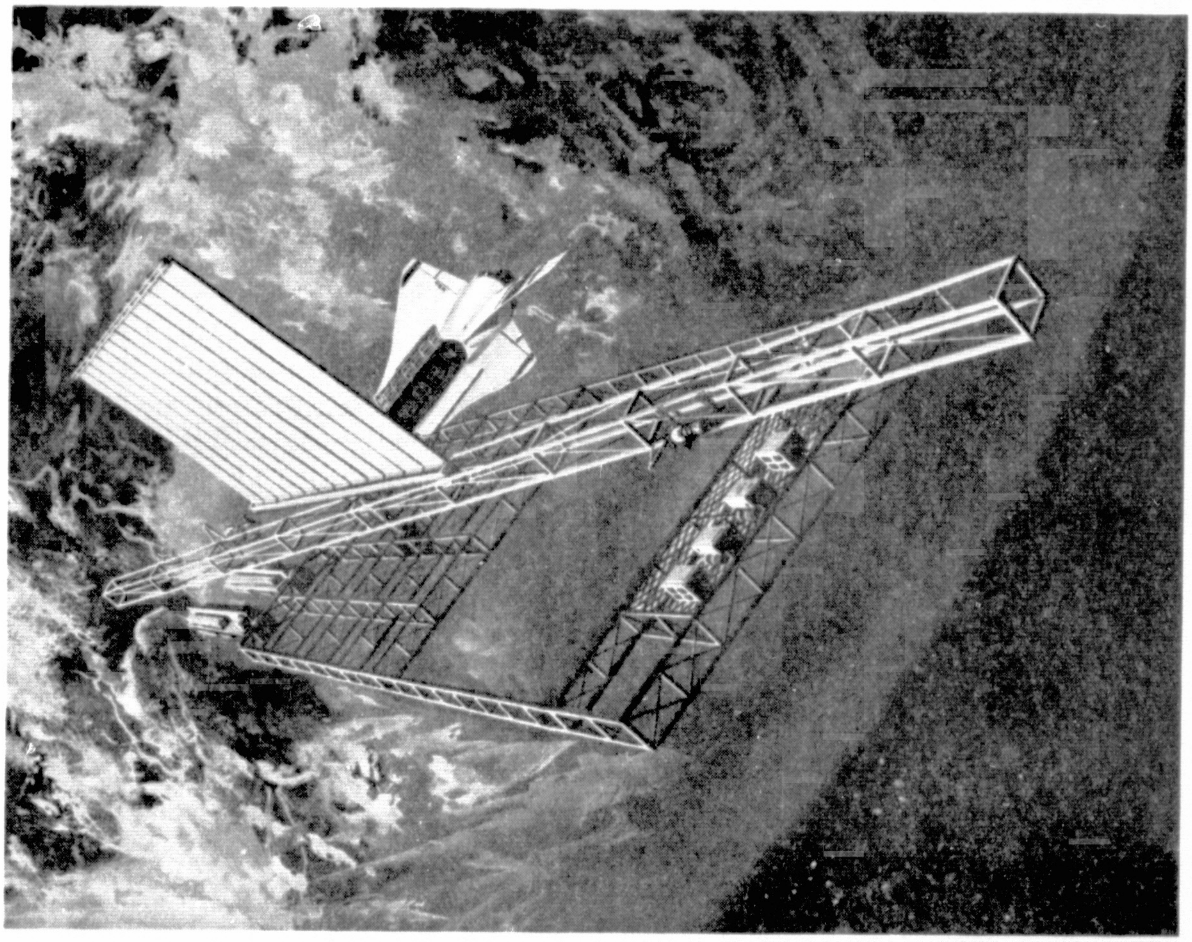


Figure 1-1 Orbital Construction Demonstration Article

1.1 GENERAL APPROACH

The Orbital Construction Demonstration Study (OCDS) objective was to define a near-term program that flight demonstrates technologies for the construction and operation of future large structures and associated subsystems to a point where hard program decisions regarding these future missions can be made in the mid 1980's. The demonstration program that evolved from this study meets the objective of compatibility with STS elements and, in fact, can enhance the shuttle potential.

The tasks performed over the nine-month study are outlined in Figure 1-2. The first task selected representative future missions for the purpose of studying issues associated with the construction and operation of typical large structures. The requirements that need flight demonstration for proof-of-concept were embodied into a conceptual OCDA design. Mission plans, program costs and schedules of this demonstration program were products of the study. Supporting analysis concentrated on the technical issues of placing a construction article into orbit in the early to mid 1980's and investigated demonstration article potential to perform continued experiments and tasks key to an active space program.

Figure 1-3 presents the major considerations that led to specification requirements for the Orbital Construction Demonstration Program. The first element was the technology and demonstration requirements for future missions. This element dictated that the ultimate operational spacecraft be studied and issues identified. The structural approach, namely the basic building block structure, the joints and the potential for ease of construction had to be evaluated in terms of applicability to both future

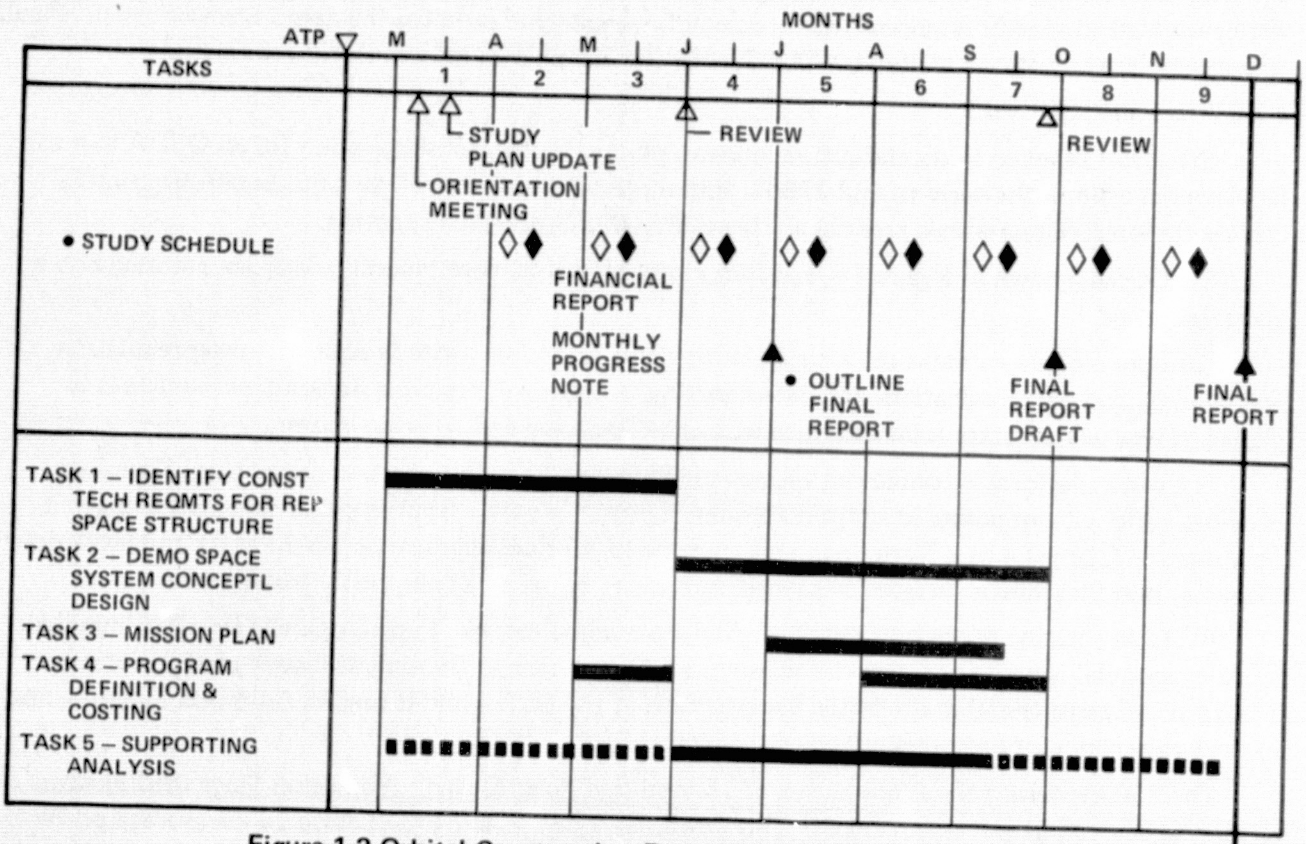


Figure 1-2 Orbital Construction Demonstration Study Schedule

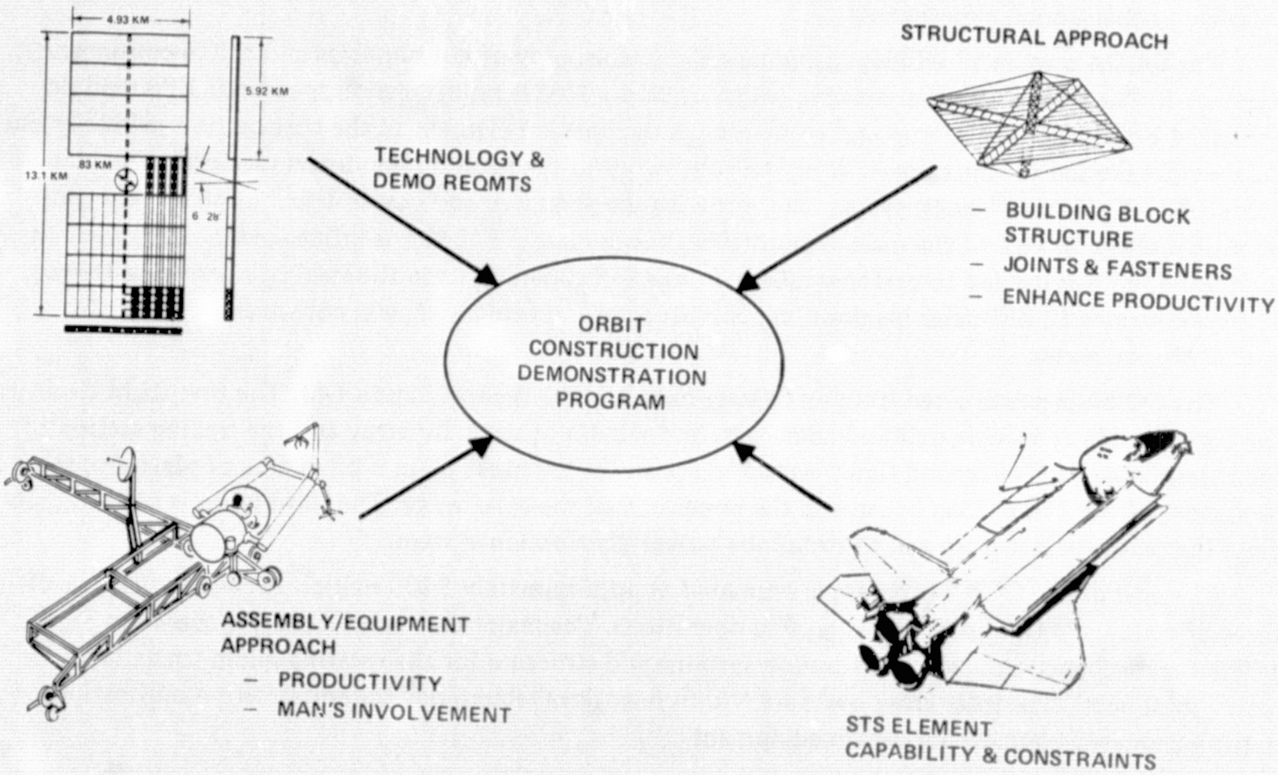


Figure 1-3 Key Elements of Study

and near-term missions. The assembly equipments and construction base concept for the future missions were evaluated to specify requirements for assembly approaches used for the demonstration itself. Finally, an assessment was made to verify that OCDA construction operations was shuttle compatible.

1.2 STUDY PRODUCTS

This effort resulted in the definition, mission plan, and program description for an OCDA that can be placed in orbit in the early to mid 1980's. Initial placement of the article requires construction in orbit and therefore establishes preliminary feasibility of this complex function.

The OCDA, shown in Figure 1-4, has four major elements: core module, platfrom, rotating boom and solar array.

The core module contains the article's subsystems, including attitude control, power regulation and control, and communications and data handling. A shuttle compatible docking mechanism is included as well as the rotary joint interface with the solar array and rotating boom.

The work platform is configured with twenty 8-m square by 4-m deep cubes or bays. Each bay provides nodal pickup points to support fixtures compatible with a Shuttle pallet of experiments and equipments. A large 24 m x 32 m open area is provided for demonstrating procedures for mounting solar blankets, thin film mirror surfaces, wire mesh and other broad area component installations.

A 110 m rotating boom outfitted with Shuttle manipulators and an equipment traveller (materials logistics module) is used to transport equipments and materials to the assigned work platform station. The boom is instrumental in the initial construction of the OCDA and is used in follow-on experiments in the construction of hardware outside the confines of the platform itself.

The 250 kw solar array is composed of 13 modified Solar Electric Propulsion Stage (SEPS) wraparound silicon cell deployable blankets. This power level was selected to provide 14 kw average power for OCDA housekeeping, 25 kw average power to support Shuttle and 40 to 70 kw average power for follow-on construction experiments.

The OCDA mass is 37,093 Kg including a 6-month supply of consumables and a 20% contingency, Figure 1-5. The electrical power system, which utilizes a NASA multi-mission spacecraft EPS module enhanced by additional batteries and regulators, is the heaviest element of the core section primarily due to wire weight needed to route power from the solar array to the rotating boom and platform. The platform (8327 Kg) is the heaviest system element with the structure and power distribution system conductors making up 78% of the mass. The rotating boom mass (7821 Kg) is influenced most by the conductors (4394 Kg) needed to perform follow-on mission experiments in the field of microwave testing. The solar array's 13 SEP solar blankets, support structure, routing wire, etc. constitutes 19% of the spacecraft dry mass.

The OCDA is constructed from an Orbiter base in three flights (Figure 1-6). The first flight deploys the core module as a single unit and adds to it, one section of the solar array and the trailing section of the rotating boom. The second flight is used to construct the inner 32 m x 32 m area of platform, the remainder of the 110 m long boom and the remainder of the solar array. The third flight is used to complete the platform structure and to install the power distribution system.

The cost of the OCDA program is estimated at approximately $400 million excluding the cost of three Shuttle flights and supporting ground operations. The major cost contributor, as shown in Figure 1-7, is the mechanisms, power distribution systems and structure for the rotating boom (included rotary joint cost). The solar array costs are within near-term technology potential with modifications in the automated blanket fabrication equipment.

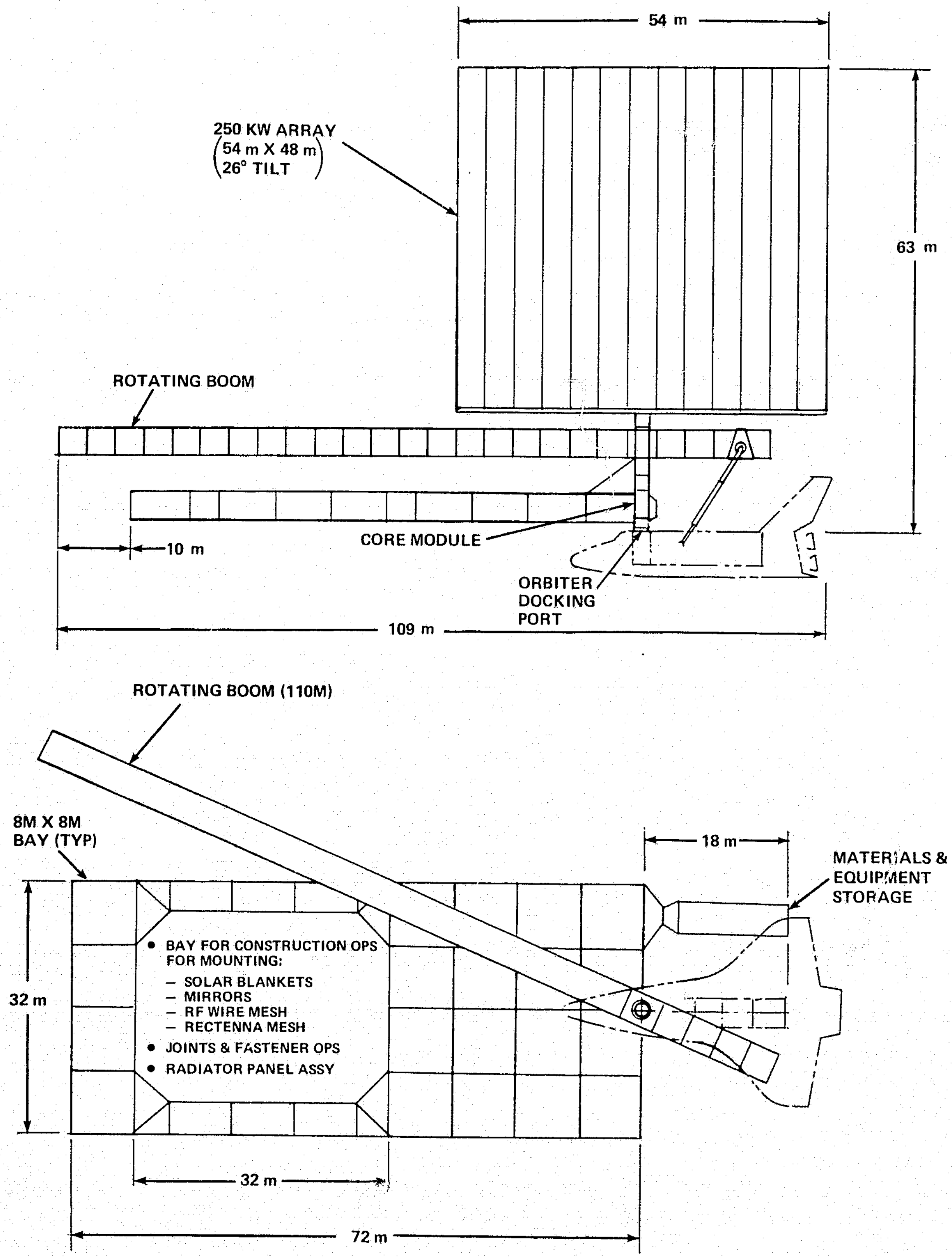


Figure 1-4 General Purpose Demonstration/Test Facility for Construction Technology

		lbM		Kg
• CORE MODULE	(5,569)		(2525)	
– STRUCTURE		316		143
– DOCKING MODULE (PASSIVE)		320		145
– COMM & DATA HANDLING		270		122
– ELECT POWER		3519 (1)		1596
– ACS MODULE & REACTION WHEELS		1144		519
• PLATFORM	(18,361)		(8327)	
– STRUCTURE		7421		3365
– PWR DISTRIBUTION		7194 (2)		3263
– PROPULSION ORBIT KEEP MODULE (2)		436		198
– ORBIT KEEP MODULE SUPT STRUCT		265		120
– LOGISTIC DOCKING PORT (2)		640		290
– PROPULSION, ATTITUDE CONTROL MODULE (2)		1907		865
– ATTITUDE CONT MODULE SUPT STRUCT		375		170
– COMM-ANTENNA'S (KU-BAND & S-BAND)		123		56
• ROTATING BOOM	(17,246)		(7821)	
– STRUCTURE		4349		1972
– MANIPULATOR & CARRIAGE		966		438
– TRAVELLER		143		65
– POWER DISTRIBUTION		9688		4394
– ROTARY JOINT		2100		952
• SOLAR ARRAY	(12,034)		(5458)	
– STRUCTURE		593		269
– SOLAR BLANKET & DEPLOY MECH.		9634		4369
– POWER DISTRIBUTION		1746		792
– ACS, SUN SENSORS (2)		28		13
– TILT MECHANISM		33		15
	TOTAL	53210		24131
	20% CONTINGENCY	10642		4827
		63852		28958
	CONSUMABLES	17938 (3)		8135
		81790		37093

1 INCLUDES 583 lbM PWR MODULE
2 INCLUDES 1818 lbM ORBIT KEEP BATTERIES & 452 lbM POWER REGULATION
3 INCLUDES 6 MONTH SUPPLY OF ACS HYDRAZINE (16,700 lbM)
6 MONTH SUPPLY OF ACS He (86 lbM)
6 MONTH SUPPLY OF ORB KEEP ARGON (1152 lbM)

Figure 1-5 Mass Summary

The program schedule shown in Figure 1-8 has been used for planning. The initial orbital placement starts in early 1984, preceded by a 3½ year design and development phase (C/D). A three-month period (early 1984) has been allocated for the three Shuttle flights required for OCDA construction. Construction of the OCDA itself was judged to meet 40% of the construction demonstration objectives. To enhance meeting the goals of the program, a 1½ year period commencing in mid 1984 following the initial placement, was allocated to "element testing" of construction/structural technologies. During this period, the OCDA is used as a facility to test structural fabrication, control system installation etc., on a small scale but larger than can effectively be handled on a single Shuttle sortie.

1.3 STUDY ADD-ON ACTIVITY

The basic 9-month study concentrated on conceptual design and definition of the initial demonstration article. The objective of a planned 5-month add-on study is to establish utility of the orbital construction demonstration facility by defining a family of experiments which demonstrate space fabrication techniques.

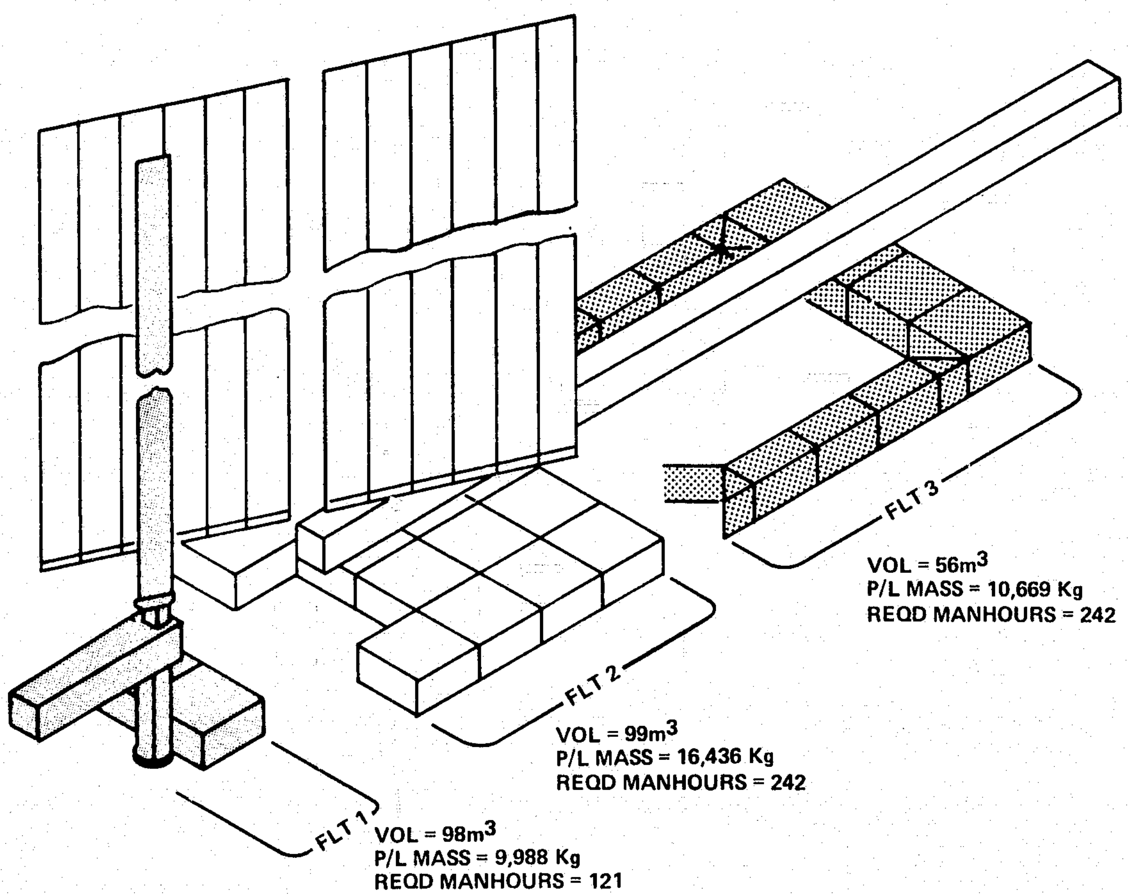


Figure 1-6 OCDA Assembly Approach (Man Assisted by Machine)

The initial placement of the OCDA was envisioned to be performed with the assistance of man in the construction process. The restrictions of room, power and flexibility imposed by operating from the Orbiter payload bay is relieved once the OCDA is in operation. The platform, rotating boom and abundant power enables the planner to schedule ambitious space fabrication experiments.

The add-on effort will define these more ambitious construction experiments and identify the impact these operations have on the basic OCDA design and orbiter interfaces. By incorporating the design requirements into the OCDA design, we will assure construction of a facility capable of demonstrating the advanced techniques needed to economically construct future spacecraft as beneficial as Satellite Power Stations (SPS).

Figure 1-9 shows a typical concept for an experiment in the 1½ year element testing phase shown in Figure 1-8. Four beam fabrication modules and the OCDA boom are the basic equipments needed to simulate the space fabrication of a large 20 m deep structural element of the ultimate SPS. Three fabrication modules are mounted to the platform "hole" and form the cap members of the larger beams. The fourth fabrication module forms the battens and stores the beams in a holding area for ultimate pick-up and assembly by manipulators.

	HIGH, $/M		LOW, $/M	
	DDT&E	1ST UNIT	DDT&E	1ST UNIT
CORE MODULE/MAST	($22.5M)	($26.9M)	($11.8M)	($18.3M)
• STRUCTURE	4.9	1.2	2.1	0.6
• DOCKING RING	0	2.3	0	1.1
• COMM/DATA HDL	1.1	3.6	0.55	1.8
• ELECTRICAL POWER	11.9	12.4	6.8	11.1
• ACS	4.6	7.4	2.3	3.7
PLATFORM	(80.3)	(32.4)	(33.7)	(16.7)
• STRUCT/MECH	55.2	13.4	23.2	6.2
• POWER DISTRIBUTION	12.3	6.1	4.1	4.1
• PROPULSION	6.1	1.7	3.1	0.8
• ACS	6.7	6.7	3.3	3.3
• COMM ANT (WB COMM)	0	0.03	0	0.03
• DOCK RINGS (2)	0	4.5	0	2.3
ROTATING BOOM/MANIP	(75.8)	(30.9)	(30.0)	(16.7)
• STRUCT/MECH	36.7	8.9	15.4	4.1
• PWR DISTRIBUTION	20.6	10.4	6.9	6.9
• MANIP/CARRIAGE	0	5.3	0	2.6
• TRAVELLER	6.9	1.2	2.8	0.6
• ROTARY JOINT	11.6	5.1	4.9	2.5
SOLAR ARRAY	(21.3)	(27.2)	(9.7)	(13.1)
• STRUCT/MECH	1.1	6.1	.5	2.0
• SOLAR BLTKS/DEPL MECH	11.8	18.2	5.9	9.1
• PWR DISTRIBUTION	8.4	2.9	3.3	2.0
TOTAL SUBSYSTEMS	(199.9)	(117.4)	(85.2)	(64.8)
PROGRAM MANAGEMENT	24.2	12.8	10.3	7.1
SYSTEM ENGR & INTEGRATION	22.0	11.7	9.4	6.5
GSE	20.0	0	8.2	0
	(266.1)	(141.9)	(113.[illegible])	(78.4)
TOTAL	(408.0)		(191.5)	

Figure 1-7 OCDA Cost Estimate (Excluding Flight Support, Shuttle Flights, Orbital Assembly)

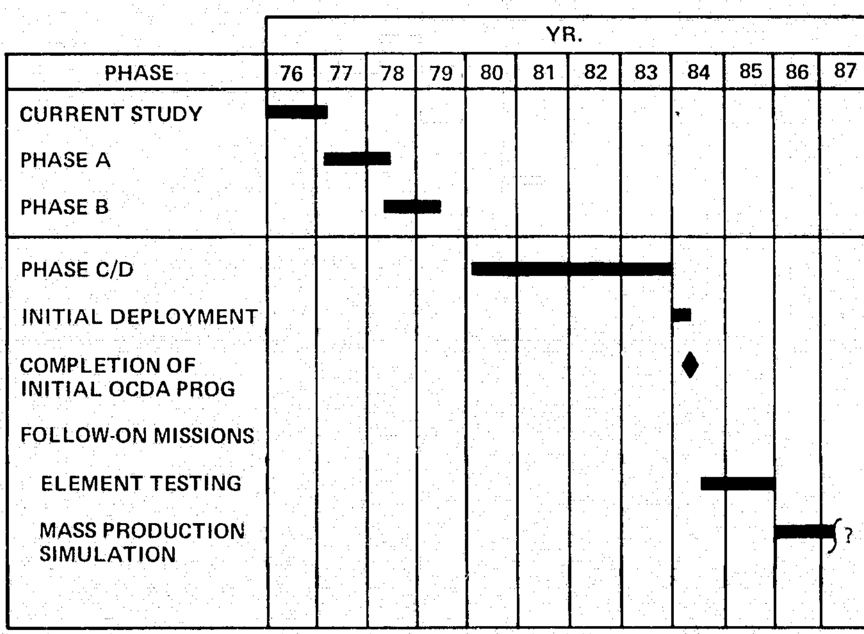


Figure 1-8 Orbital Construction Demonstration Article Planning Schedule for Selected Approach

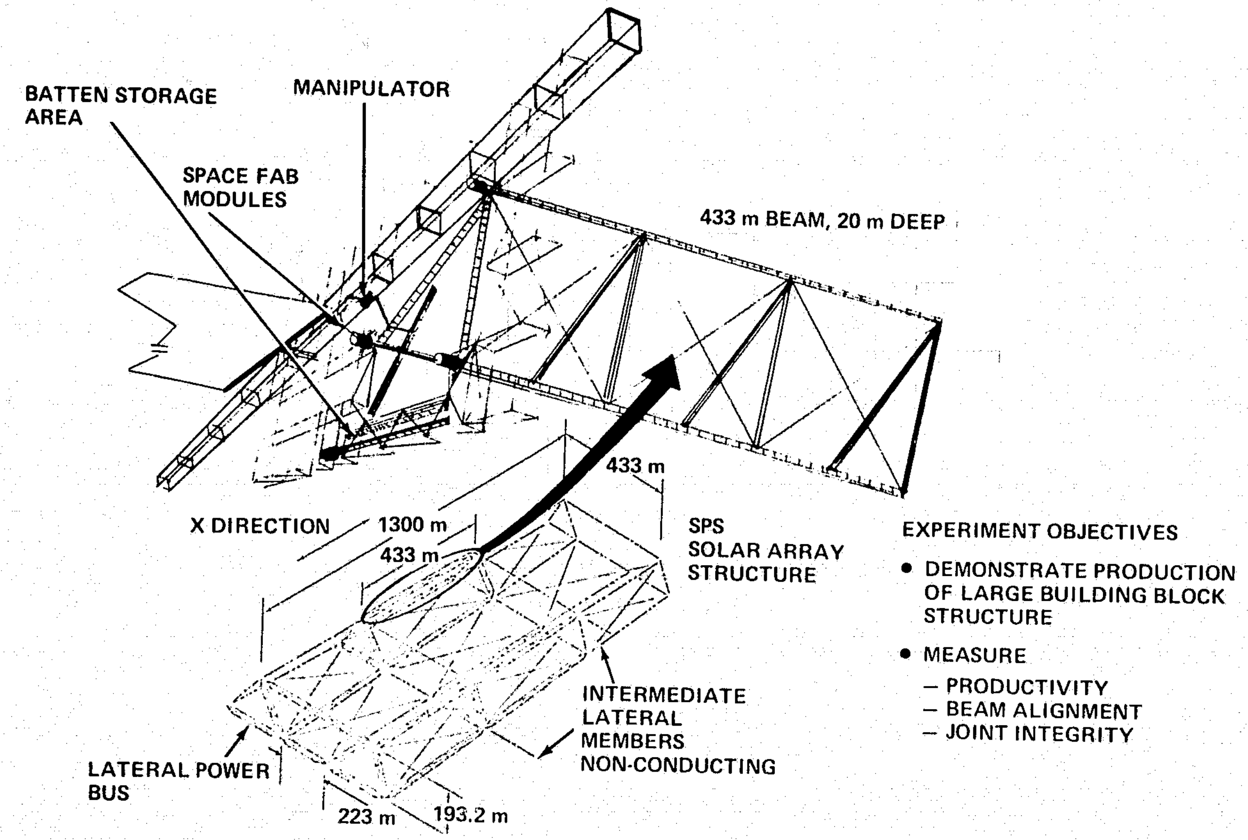


Figure 1-9 Typical Element Testing Phase Experiment

Section 2

REQUIREMENTS FOR CONSTRUCTION

The Orbital Construction Demonstration Study effort was directed toward definition of the requirements that future Spacecraft utilizing ultra-large structures impose on near-term construction technology. The approach used during the first task (see Figure 1-2) was to identify and describe potential large structure by reviewing future missions. A few representative missions were then selected for the purpose of delineating construction issues. The issues were studied to determine a near-term orbital demonstration program that would provide sufficient confidence in the state of technology to start development of these future missions. Those issues requiring orbit demonstration were embodied into several programs of varying cost and complexity and a program selected that met a high percentage of demonstration objectives, had reasonable cost, and offered potential for continued usage as a construction technology test facility.

The point of departure for selection of representative future missions was a data base provided by such documents as the "Outlook for Space" and The Aeroscope Corporation's "Study of the Commonality of Space Vehicle Applications to Future National Needs" (ATR-5 (7365)-2). To ensure that the sample of representative future missions was reasonably balanced, space programs were divided into seven general classifications for study, namely:

- Communications
- Navigation
- Earth Observation
- Energy Systems
  - Generation
  - Transmission
  - Power Relay
- Radio Astronomy
- Illumination
- Space Colonization

In all, 40 future missions were reviewed. This number was reduced to 10 candidates, Figure 2-1, by eliminating those concepts that did not require space construction for deployment or to achieve required structural accuracy. The exception to this criteria was in the field of navigation and space colonization where the concepts were not sufficiently defined or considered too far in the future to benefit from a near-term demonstration program. A further reduction in candidate representative missions was made by eliminating systems whose requirements are embodied by other systems. This step eliminated the communications antennas and radio astronomy antennas in that their requirements were embodied in those of the radiometer and power transmission system phased array.

The remaining five representative structures, Figure 2-2, were studied for technology requirements and categorized into 12 problem areas needing orbital construction demonstration and test.

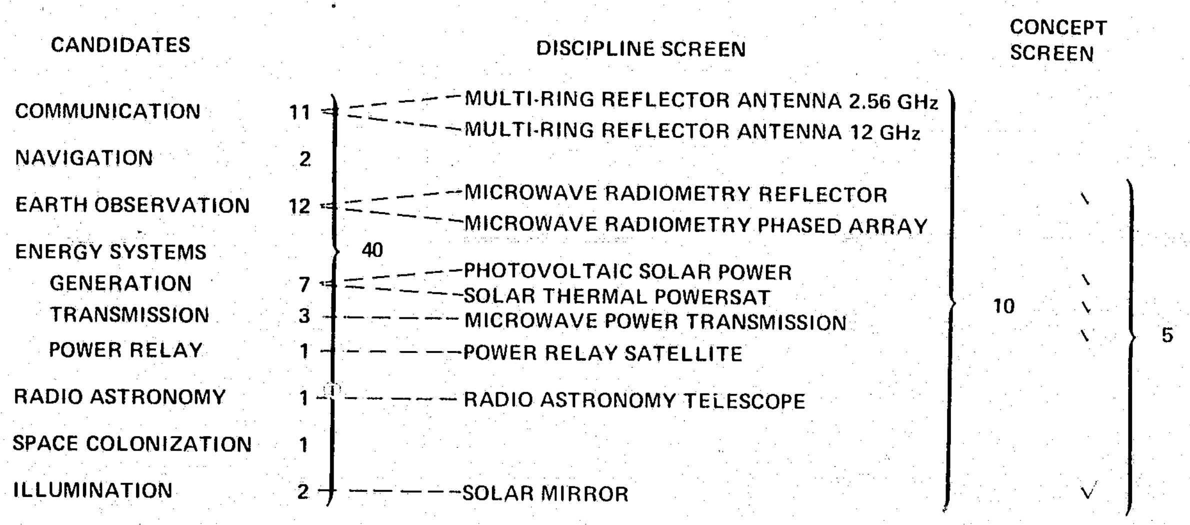


Figure 2-1 Representative Mission Screen

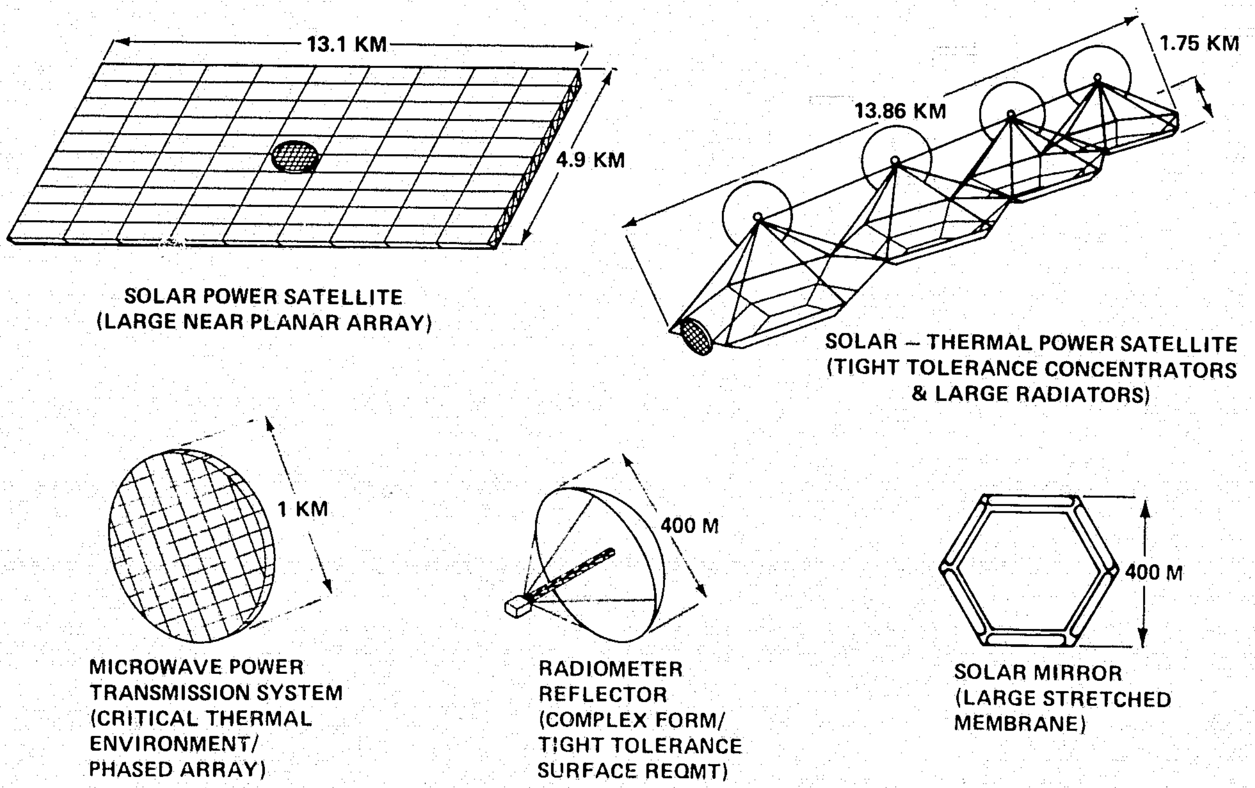


Figure 2-2 Recommended Representative Structures

2.1 DEMONSTRATION/TEST OBJECTIVES

Seventy-two demonstration/test objectives were identified for the problem areas shown in Figure 2-2. Delineation of these objectives can be found in the 6th monthly progress report, NSS-OC-RP006. The topic for each of these objectives is listed in Figure 2-3 with a numerical weight assigned to each area that indicates the need for an orbital demonstration. Figure 2-4 provides the scale and criteria used to assign the demonstration need weight. The status of technology, hardware availability and ground test potential were considered in assessing the benefits an orbital demonstration would have to the solution of a given construction problem.

A typical factor considered in determining the applicability of ground demonstration to meeting objectives is summarized in Figure 2-5. The large size and light weight of typical space structure complicates ground handling. The beams allowable loads would be exceeded during simple logistics movements of the hardware. Simulation of zero-g for as large a structural element needed in future missions was found to be difficult and potentially costly using existing neutral buoyance facilities.

Analysis and design methods development also need the data space construction demonstrations can provide. The analytical techniques for modelling large flexible structures can be refined as test information from orbital demonstration becomes available. The long-period dynamic response to thermal excitation is a problem identified that needs orbit verification tests of analytic methods. More precise approaches for modelling gravtiy gradient forces and moments using series expansion techniques could be verified through orbit demonstration.

Assessment of construction productivity of man and machine is needed by the mission planner to accurately schedule the construction of future spacecraft. An orbit demonstration would verify and fine-tune the data accumulated in ground simulation. This is particularly true for the installation of subsystems and associated secondary structure. Methods for handling installation of propulsion units used for attitude control is an example of an assembly procedure development that would benefit from an orbit demonstration program.

Of the 72 problem areas identified, the demonstration need weight for 44 ranked seven or above (Figure 2-3). Space experimentation of construction technique and structural approaches is a necessary endeavor to verify, in the total operational environment, along with the operations and structural technology needed to deploy and assemble large structures in space.

2.2 CONSTRUCTION APPROACH

The five representative future missions were studied functionally for construction problems, and one, the Microwave Power Transmission System (MPTS) antenna, was studied in detail to determine near-term construction demonstration requirements. The data base on the MPTS is greater than other configurations identified. The work performed by Raytheon/Grumman on the basic antenna design and the assembly studies performed by Martin provided a good point of departure for penetration into construction issues.

The basic approach was to first study construction techniques for the structure, considering different support equipment and structural approaches. The construction base showing the most potential was used to analyze subsystem installation, fabrication approach, logistics requirements and habitation needs.

PROBLEM AREA	DEMO/TEST OBJECTIVE	DEMO NEED WEIGHT
STRUCTURES	1) BUILDING BLOCK STRUCT FAB AND/OR DEPLOY 2) JOINT ASSEMBLY PROCEDURES 3) MAN/MACHINE/INTERACTION 4) LARGE ELEMENT MATING 5) SECONDARY STRUCTURE INSTALLATION 6) MEASURE PRODUCTIVITY 7) ATTITUDE CONTROL DURING CONSTRUCTION 8) THERMAL CYCLING DURING CONSTRUCTION 9) ACCURACY & INTEGRITY TESTS 10) STRUCTURAL REPAIR 11) STRUCTURE/CONTROL/INTERACTION	6 8 8 9 8 6 7 6 8 7 7
SOLAR ARRAY	1) CONSTRUCTION & DEPLOYMENT 2) LOW COST, HIGH EFFICIENT SPACE FAB BLANKET 3) ARRAY TO STRUCT INSTALLATION 4) CONCENTRATOR INSTALLATION 5) THERMAL CYCLE 6) FAULT ISOLATION & REPAIR	8 8 7 7 6 7
POWER DISTRIBUTION	1) INSTALL INTEGRATED STRUCTURE/BUS SYSTEM 2) INSTALL DEDICATED SYSTEM WITH SWITCH GEAR & CIRCUIT PROTECTION 3) INSTALL STORAGE SYSTEM 4) INSTALL POWER CONDITIONING UNITS 5) INSTALL ROTARY POWER TRANSFER DEVICE 6) HI VOLTAGE OPERATION 7) LEAKAGE PREDICTION 8) FAULT ISOLATION & REPAIR	 5 7 8 8 7 7
POWER TRANSMISSION	1) DC TO RF CONVERSION IN STEPS 2) INTEGRATED PROOF-OF CONCEPT 3) THERMAL CYCLING TESTS ON WAVE GUIDES & PHASE CONTROL 4) IONOSPHERE TESTS 5) GEO PERFORMANCE (HI VOLTAGE & START) 6) LIFE TESTS 7) DEMO TRANSMISSION TO GROUND	8 10 6 4 8 4 8
PROPULSION	1) INSTALL PROPULSION UNIT FOR ATTITUDE CONTROL & STATION KEEPING 2) VERIFY EFFECTS OF EXHAUST PRODUCTS 3) FAULT ISOLATION & REPAIR	7 3 5
STABILIZATION & CONTROL	1) CONTROL OF LARGE FLEXIBLE BODIES USING CENTRALIZED & DISTRIBUTED SYSTEMS 2) SURFACE CONTOUR CONTROL 3) POINT 1 LARGE MASS RELATIVE TO 2ND 4) STATIONKEEPING 5) FAULT ISOLATION & REPAIR	7 8 7 5 4

PROBLEM AREA	DEMO/TEST OBJECTIVE	DEMO NEED WEIGHT
REFLECTOR MIRROR FACETS	1) PLACEMENT & INSTALLATION 2) POINTING & CONTROL ON FLEXIBLE BODY 3) FAULT ISOLATION & REPAIR	9 10 7
RADIATORS	1) POSITIONING & ASSEMBLY OF RADIATOR ELEMENTS 2) CONSTRUCT GAS TIGHT JOINTS 3) FAULT ISOLATION & REPAIR	8 6 4
THERMAL CAVITY	1) POSITIONING & ASSEMBLY 2) GAS TIGHT JOINTS 3) CAVITY PERFORMANCE THROUGH CONSTRUCTION 4) CONTROL WITH ROTATING MACHINERY	8 6 8 8
LARGE MIRROR SURFACE	1) POSITIONING & ASSEMBLY 2) CONTOUR CONTROL 3) EFFICIENCY MEASUREMENT 4) LIFE TESTING	8 8 5 4
ASSEMBLY OPERATIONS	1) INITIAL PLACEMENT OF CONSTRUCTION PLATFORM 2) SITE LOGISTICS 3) RESUPPLY & STORAGE 4) HABITATION 5) SITE COMMUNICATIONS 6) SITE LIGHTING 7) RADIATION SAFETY (GEO) 8) PRODUCTIVITY GOALS 9) REMOTE CONTROLLED MANIPULATORS 10) SPARE FABRICATION (AUTO ASSEMBLY) 11) USE OF EVA 12) FAULT ISOLATION & REPAIR OF CONSTRUCTION EQUIPMENTS	8 7 6 4 5 5 6 8 7 8 6 6
PROCESSES	1) FASTENER OPTIONS (WELD, BOND, ETC) 2) FAB IN METALLICS & NON METALLICS 3) VAPOR DEPOSITION FOR REPAIR 4) CRYSTAL GROWTH 5) PURE METALS 6) PHARMACUTICALS	7 6 8 8 8 8
MISSION OPS	1) COMMUNICATIONS 2) REMOTE CONTROL FROM GROUND 3) MISSION PLANNING	5 8 4

Figure 2-3 OCDA Mission Objectives

	DEMO NEED WGT.				
	1 2	3 4	5 6	7 8	9 10
TECHNOLOGY	FULLY DEVELOPED & SPACE QUAL'ED	PARTIALLY DEVELOPED & PLANNED FOR SPACE DEMO IN NEAR TERM	KNOWN BUT NOT DEVELOPED & WOULD BE AUGMENTED BY SPACE DEMO	NOT KNOWN BUT CHANCE OF BECOMING KNOWN GOOD IF SPACE DEMO USED	NOT KNOWN, SPACE DEMO MANDITORY TO FINDING SOLUTION
HARDWARE	OFF-THE SHELF OR PROTOTYPE AVAILABLE WITH REQ'D FUNCTION & PERFORMANCE	FUNCTIONALLY EQUIVALENT HARDWARE AVAIL NEEDING MODIFICATION	FUNCTIONALLY EQ'V. HARDWARE BEING DEVELOPE. DEVELOPMENT NEEDING ORBIT VERIFICATION	NO HARDWARE IN USE – NEEDS SPACE DEMO DATA INPUT	HARDWARE NOT AVAILABLE UNLESS BREAKTHROUGH ACHIEVED VIA SPACE DEMO
GROUND TEST	CAN FULLY BE ANSWERED BY GROUND TEST	DESIRABLE TO HAVE GROUND TEST AUGMENTED WITH FLT TEST	HIGHLY DESIRABLE TO HAVE GROUND TEST AUGMENTED WITH FLT TEST	MANDITORY TO HAVE GROUND AUGMENTED WITH FLT TEST	ONLY FLIGHT TEST WILL GIVE ANSWER

Figure 2-4 Space Demonstration Value Criteria

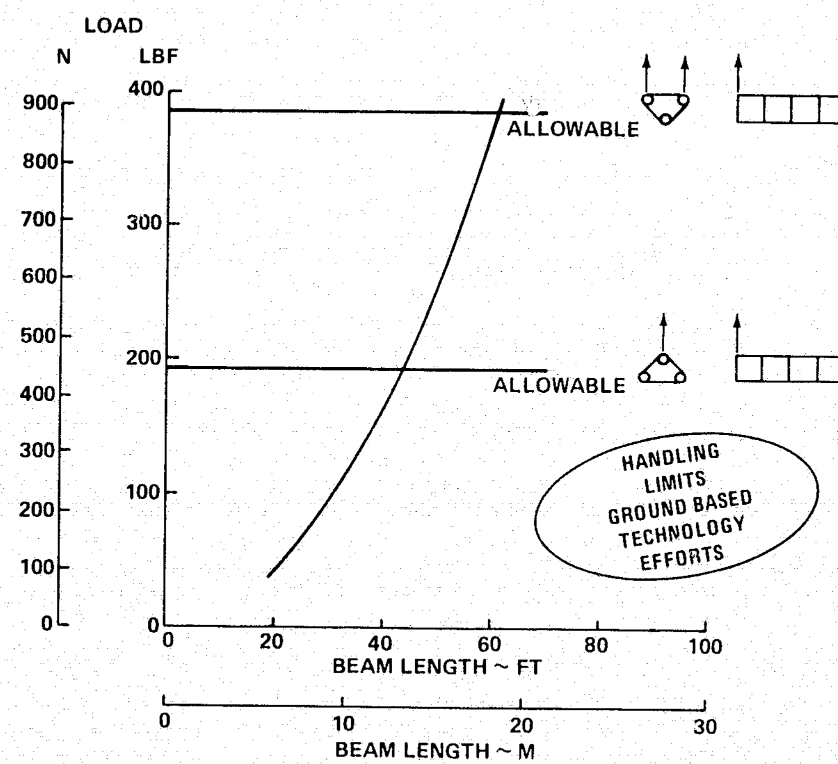


Figure 2-5 Ground Handling Limitations on Typical Space Beam

As a means of assessing the quality of construction approaches, a study was done to determine the productivity requirements for assembly of the SPS. Consideration was given to such parameters as construction base costs, crew rotation policy, and Shuttle crew transport capability. Figure 2-6 is a plot of the relationships between SPS construction cost ($/kw) and the $/manhour that can be allocated given a production rate (Kg/manhour). It was found that construction base costs have a significant impact on productivity requirements. At a base cost of $20 x 10^6/man, (amortized cost of $7.25 x 10^6/manyear) an average productivity of between 40 and 100 Kg/manhour (LEO assembly or 60 to 110 Kg/manhour (GEO assembly) would be required to meet SPS cost targets of 75$/kw. This suggests that a compromise between the level of automation and the capital cost of construction equipment is needed. High production rates are not the only consideration in achieving cost effective power from space.

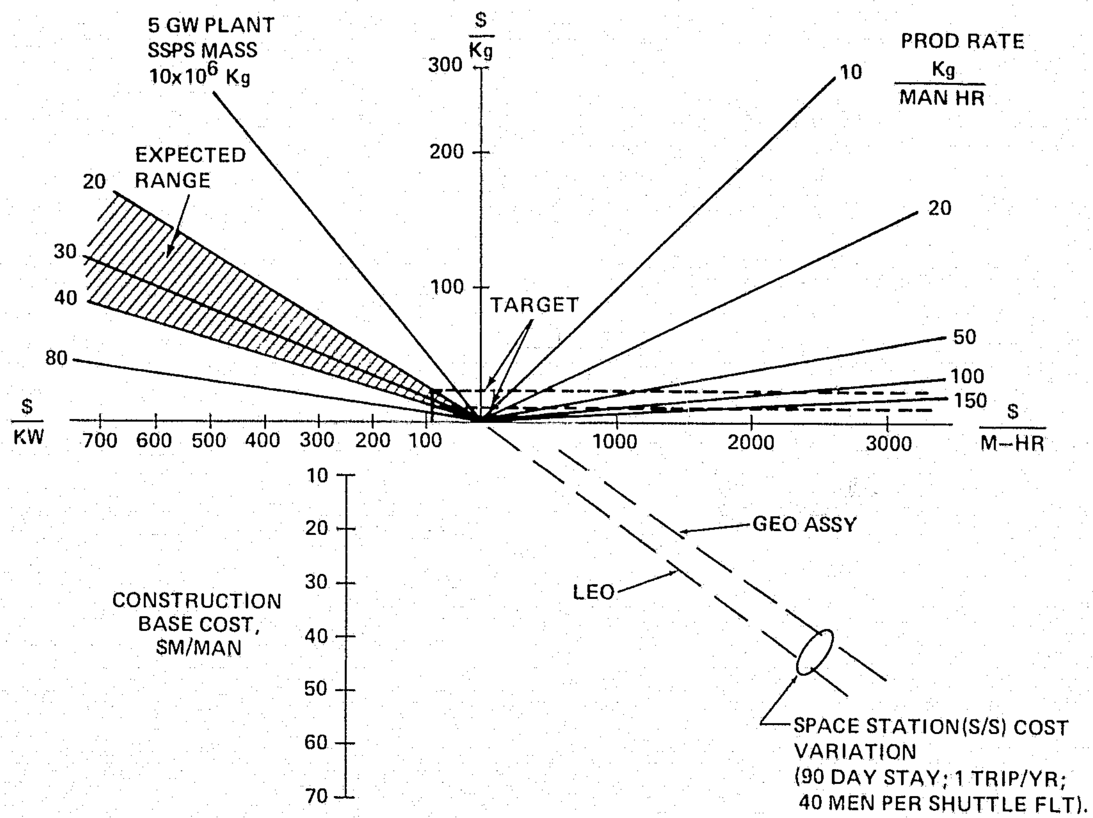


Figure 2-6 Productivity Relationships

Figure 2-7 presents an overview of four construction options studied for MPTS assembly. The first is the Martin "Post Walker" approach in which a set of equipments, including two manipulators, is supported on bases attached to the antenna vertical posts. After completing one structural cube (18 x 18 x 25 m) the manipulator base is swivelled or "walked" to the just-completed set of vertical posts. The second approach uses a construction jig, which is a beam 830 m long and 24 m deep, that contains 46 sets of manipulators and construction equipments. This approach facilitates parallel production of an entire row of antenna structure. The third approach uses a "long boom" attached to a centrally located base. Equipments for construction are mounted to the "long boom" for access to the immediate assembly location. The fourth approach utilizes a travelling fabrication unit which forms a continuous spiral, 25 m deep circumferential and periodically installs spacers (radial elements) to build up a spoke structural arrangement.

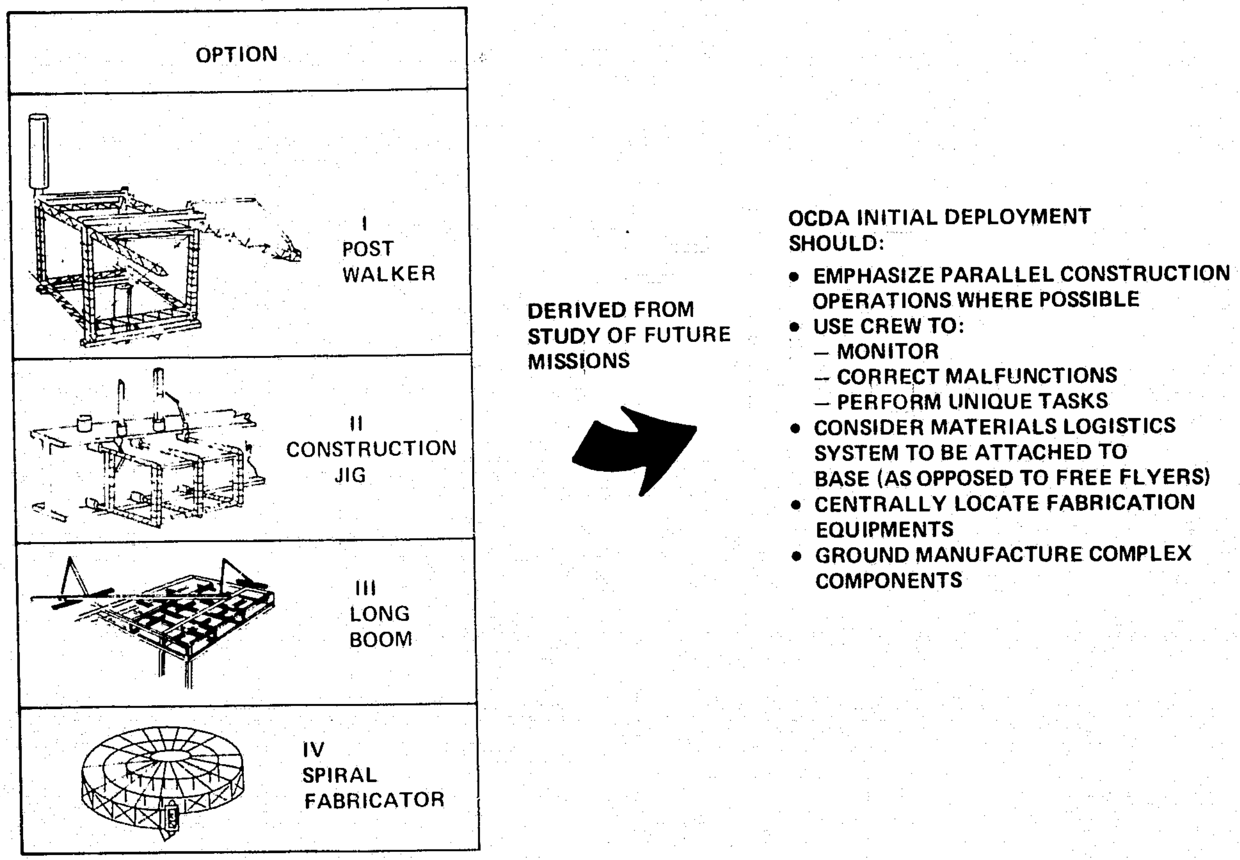


Figure 2-7 Guidelines Used for Selection of Assembly Techniques for Initial OCDA Deployment

Option II, "the Construction Jig," showed the greatest potential for meeting productivity requirements of the MPTS, though more analysis and base definition in needed to determine capital costs of the base. Because of this potential, the construction jig was then used to assess secondary structure assembly, subsystem installation, logistics requirements and crew size.

The study of construction techniques led to the following general conclusions for future ultra-large structure assembly:

- Emphasize parallel construction operations where possible
- The crew should be used to monitor, correct malfunctions, perform unique installations and repair automated machinery
- The logistics system for moving materials around the construction base should be attached to the based structure. Devices like long-rotating booms were used for this function
- The structure should be space-fabricated in a centrally located facility to reduce capital costs
- Complex, close tolerance components, such as the MPTS microwave subarrays, should be ground manufactured.

These principals where used to formulate concepts for the near-term OCDA program. The demonstration article should assess, either during initial OCDA construction or as part of the follow-on experiment, mass production techniques, attached logistics for materials handling, and complex tight

tolerance subsystem installations. The OCDA should represent a scaled down version of the basic structure for mounting automated equipments and provide the power, stabilization and materials handling facilities to enchance technology experiments that lead to the ultimate construction base makeup.

2.3 BUILDING BLOCK STRUCTURE & JOINTS

Once the top level construction approach groundrules were established, a study of building block structure and joints was made to select a family of options for demonstration on the OCDA, either in the initial deployment or as follow-on experiments. This study concentrated on the study of deployable beams and the work performed by Grumman under contract NAS8-31876, "Space Fabrication Techniques Study Program," used as the data base for the definition of space fabricated beams and associated equipment. The centroidal joint and lap joint were studied in terms of ease of construction, and mass as it applies to future mission applications.

Figure 2-8 summarizes the result of an industry search of prepackaged deployable structures. After an initial screening of 12 candidates, seven concepts were selected for further evaluations:

- A2 - The Martin folded beam concept allows the upper longeron and frames to lie flat against the two lower longerons
- A6 - A coilable lattice astromast whose continuous longerons are coiled to stow the configuration
- A7 - Rockwell International's "Y" sahped girder concept, consisting of three webbed beams hinged to a central shaft for stowing. The outer tubular beam caps (3) culminate at each end of the girder to an integral end coupling
- A9 - An articulated lattice astromast which consists of rigid triangular battens and longeron sections which pivot at each bay for stowing
- A10 - Grumman's building block configuration, a double-folded beam designed to achieve a minimum stow volume. The frames (battens) and longitudinal members are foldable. The deployed structure is rigidized by two locked telescoping diagonal members.
- A11 - The Boeing Warren-trussed triangular beam. The rigid frames provide pivots at their apex to allow the adjacent frames to stow. The longitudinals are hinged at their midspan and pivot at each frame to allow them to stow between the folded frames
- A13 - Grumman's continuous longeron, batten foldable beam.

Each prepackaged deployable structure candidate was configured to a 1.5-m deep x 23-m long trussed beam. Each concept was then sized for an end column compression load of 576 lb ultimate at a temperature of 100°F. Tubes of 0.015 minimum gage, 2219 aluminum alloy was used for the structural element of each concept with the exception of the coilable astromast which uses S-glass. Figure 2-9 presents the relative merit of the candidates as to weight, packageing volume and launch costs. The astromast concepts A6-2 and A9-1 require the least launch dollars when utilizing the Heavy Lift Launch Vehicle (HLLV), and concept A9-2, the articulating lattice astromast, and Grumman's A10 and A13 concept requires the least Shuttle launch dollars.

A space beam fabrication approach was then compared with concept A-13 for application to a near term OCDA which requires in the neighborhood of 1000 to 2000 m of 1-m deep beams. Figure 2-10 summarizes this comparison. The maximum amount of deployable structure that can be carried in the Shuttle cargo bay is limited by volume rather than mass. A total of 8944 meters of deployable structure, with two supporting pallets, can be carried. The amount of space-fabricated structure that can be carried is limited by the Shuttle cg envelope. A maximum of 18,340 meters of space-fabricated structure and the associated machinery can be delivered.

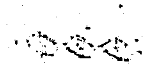
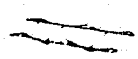
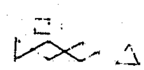
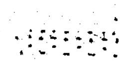
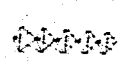
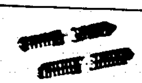
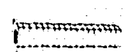
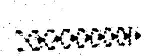
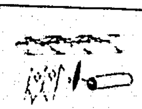
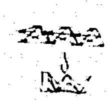
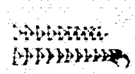
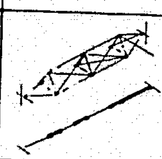
CONCEPT	SCHEMATIC	COMMENTS	RECOMMENDATION
A-1 FOLDED BEAM		• EFFICIENT STRUCTURE • HEAVY DUE TO PULLEYS, CABLES AND LATCHED JOINTS • LOW PACKAGING DENSITY	• REJECT
A-2 FOLDED BEAM COLLAPSED ✓		• GOOD STRUCTURAL CONCEPT • HEAVY DUE TO THE NUMBER OF PYROTECHNICS REQUIRED TO LOCK THE TELESCOPING DIAGONAL • FAIR PACKAGING DENSITY	• CONSIDER FOR BASIC BUILD-ING BLOCK STRUCTURE
A-3 LAZY-TONGS		• FLEXIBLE STRUCTURE • LOW LOAD CARRYING CAPABILITY • HIGH PACKAGING DENSITY	• REJECT
A-4 THREE AXIS LAZY TONG		• POOR STRUCTURE • LOW BENDING & TORSIONAL STIFFNESS • HIGH PACKAGING DENSITY	• REJECT
A-5 EXTENSIBLE TRUSS		• LOW TORSIONAL STIFFNESS • HEAVY SINCE LAZY TONGS ARE BASICALLY INEFFICIENT COLUMN MEMBERS • HIGH PACKAGING DENSITY	• REJECT
A-6 COILABLE LATTICE ✓		• HEAVY SINCE LONGITUDINALS ARE SOLID COIL SPRING MEMBERS FOR COILING • MATERIALS APPLICATION MAY BE LIMITED • GOOD PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCT-URE
A-7 FOLDED SPACE GIRDER ✓		• INEFFICIENT COLUMN MAY BE HEAVY • RIGGING FOR ALIGNMENT COMPLEX • FAIR PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCT-URE
A-8 BOX BELLOWS		• CLOSED SECTION MAY BE THERMALLY UNDESIRABLE • HIGH PACKAGING DENSITY	• REJECT
A-9 ARTICULATED LATTICE ✓		• EFFICIENT BEAM • HEAVY DUE TO COMPLEXITY AND NUMBER OF JOINTS • GOOD PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCT-URE
A-10 DOUBLE FOLDABLE ✓		• EFFICIENT STRUCTURE • HEAVY DUE TO COMPLEXITY & NUMBER OF HINGED JOINTS • HIGH PACKAGING DENSITY	• CONSIDER FOR BASIC BUILD-ING BLOCK STRUCTURE
A-11 FOLDED-BEAMS COLLAPSED ✓		• EFFICIENT BEAM • HEAVY DUE TO LARGE NO OF HINGED AND LATCHED JOINTS • HIGH PACKAGING DENSITY	• CONSIDER FOR BASIC BUILDING BLOCK STRUCT-URE
A-12 TRIANGULAR WIRE		• NO DIAGONAL BRACING, LOW SHEAR STIFFNESS • EULER BUCKLING MAY BE LOW • HIGH PACKAGING DENSITY	• REJECT
A-13 GRUMMAN CONTINUOUS LONGERON		• GOOD STRUCTURAL CONCEPT • CONTINUOUS LONGERONS ELIMINATE STRUCTURAL DEAD BAND RESULTING FROM JOINT CLEARANCES • GOOD PACKAGING DENSITY?	• CONSIDER FOR BASIC BUILDING BLOCK STRUCTURE

Figure 2-8 Summary of Prepackaged Deployable Structures

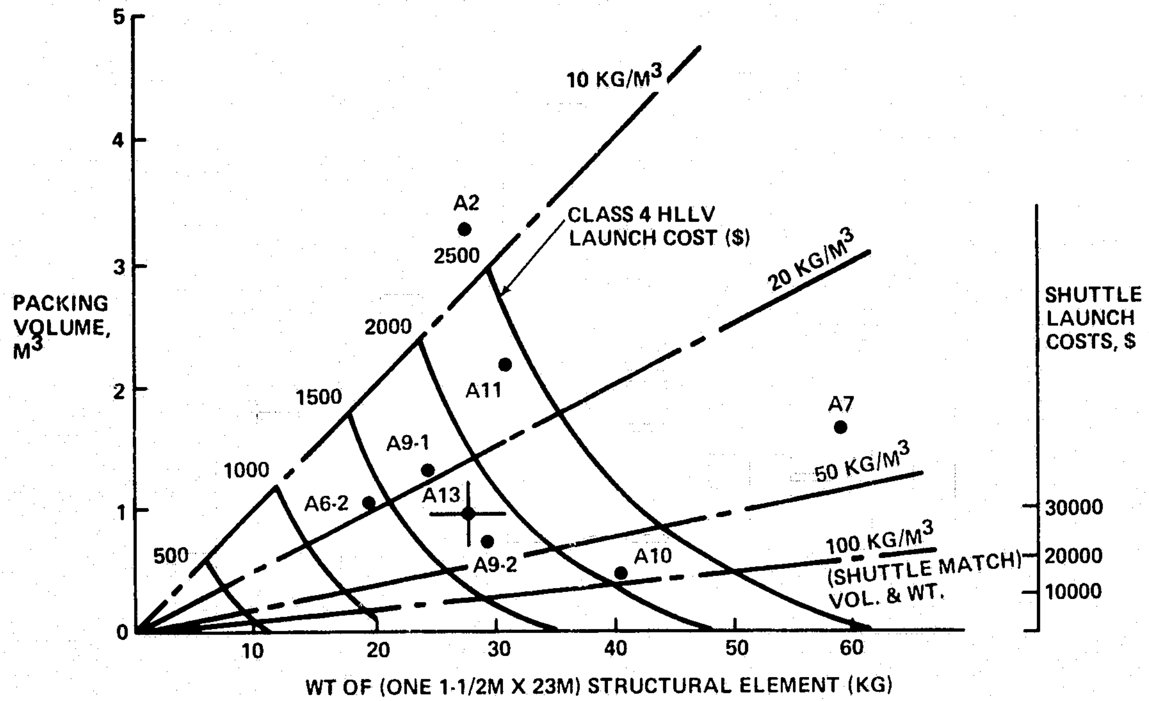


Figure 2-9 Concept Ranking—Weight, Volume & Launch Costs

DEPLOYABLE

- STOWED VOLUME = 0.02094 m^3/m
- UNIT MASS = 1.5 KG/m
- MASS/VOLUME = 71.8 KG/m^3

SPACE FAB

- FAB MODULE VOLUME = 62.4 m^3
- FAB MODULE MASS = 5442 KG
- BEAM UNIT MASS = 6848 KG/m
- STOWED VOLUME = .0019 m^3/m
- MASS/VOLUME = 360 KG/m^3

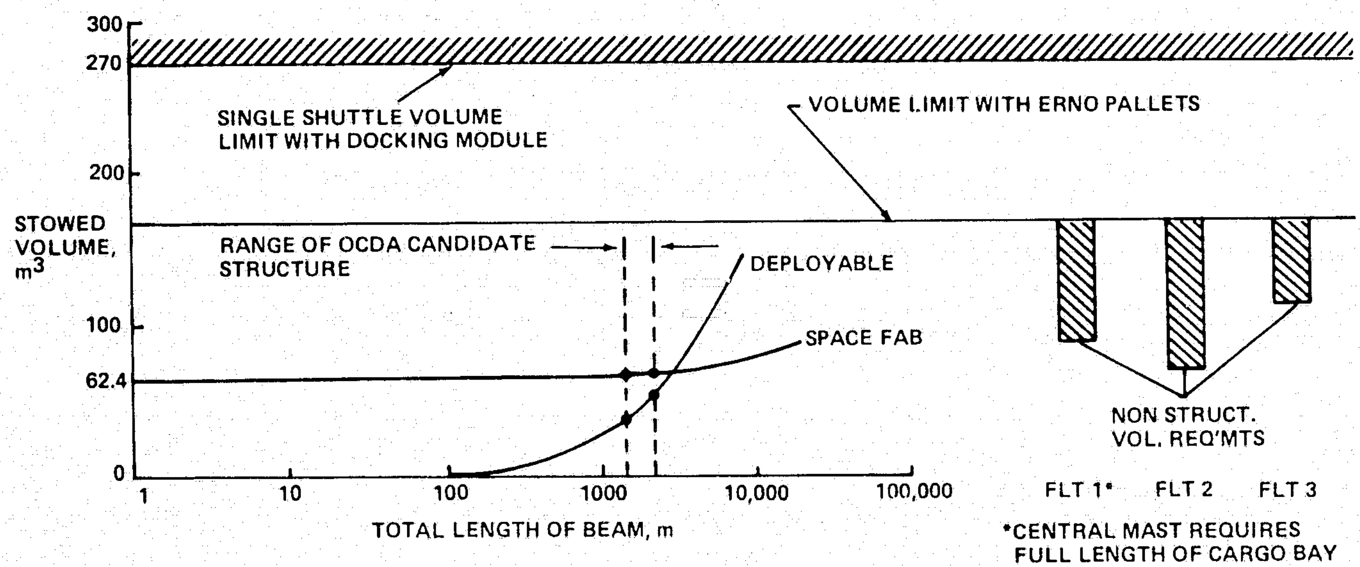


Figure 2-10 Deployable vs Space Fabrication

Although the study trends indicate that space-fabricated structure is very beneficial for constructing the ultimate future mission structure (specifically the SPS), the small amount of structure required by an OCDA size demonstration may not warrant the approach. If we do not fabricate the initial OCDA, the platform can be used to demonstrate space fabrication during follow-on missions. The key decision to be made then is to determine if demonstrating space fabrication techniques on the initial construction of the OCDA is a valuable technology contribution to justify the added cost, or is it sufficient to wait until the OCDA platform is constructed using deployables before space-fabrication experiments are performed. This study opted for the more conservative approach of utilizing deployables for initial OCDA construction and to perform space-fabrication concepts during follow-on OCDA experiments.

A typical triangular building block beam and two basic joining methods (the lap and the butt (centroidal) joint) for assemblies of one cap member and two posts is shown in Figure 2-11. A lap joint is defined as any joint where load lines or centroids do not intersect at a common point and thereby produce a moment into the joint. A centroided joint is defined as one where all load lines intersect and balance at a common controidal point.

Criteria used for evaluating candidate joints include methods of attachment (weld, bond or mechanical); ease of alignment and possibility of realignment; joint integrity which includes reliability, producibility and quality control requirements. Unique requirements such as electrical conducting or isolated structural joints must also be eventually evaluated. The productivity of the joining systems which relates number of joints per unit time to cost will be a function of the degree of automation and modular design employed. After analysis of the two joint concepts, the centroidal joint was recommended for use in future missions and adopted for the OCDA design approach. Further technology level efforts are needed to come to a final understanding of this important trade-off.

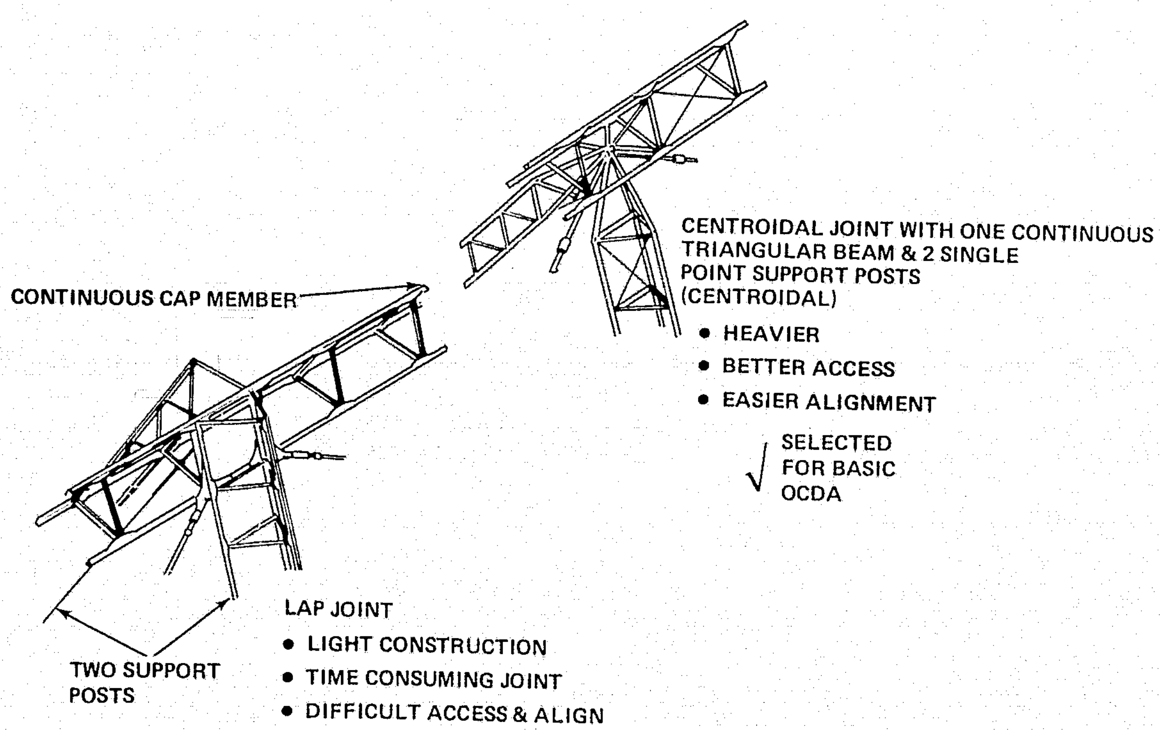


Figure 2-11 Candidate Joint Approaches

Section 3

ORBITAL CONSTRUCTION DEMONSTRATION ARTICLE

This section summarizes (1) the rationale for selecting a multipurpose construction facility as the near-term demonstration article and (2) the definition of the OCDA system including structural arrangement, design requirements and subsystems. The demonstration objectives identified in the first-part of the study were used to formulate two basic OCDA programs. The first program starts with a construction base with a sufficiently large power source to perform follow-on experiments that simulate the space fabrication techniques needed for future system applications. The second program starts with a large 1 Mw power source to pave the way for a proof-of-concept for space base solar power generation and transmission. The cost of the programs and risk were factors that led to selection of a multipurpose construction facility that has the potential to build the pilot plants needed for space power generation proof-of-concept, large radiometers and night illuminators.

3.1 ALTERNATE CONCEPTS

The description of two basic OCDA programs are summarized in Figure 3-1. Each program was evaluated for one growth mission giving four concept options that span a range in complexity and potential cost. The first option, part of Program 1, is designed to assemble a multipurpose construction demonstration base which is used to perform basic technology and operations experiments associated with construction of large structures in space. The second option tests the growth potential of Option 1 by utilizing the construction base to assemble a 100 m parabolic antenna. Option 3 is the starting point for the second program. It utilizes a large 1 Mw solar array to demonstrate the ability to construct a large power source. The fourth option is the growth version of Option 3 (Program 2). A microwave power transmitter antenna is added for purposes of "proof-of-concept" for SPS by transmitting power to the ground with 10 kw output power.

3.1.1 Program 1

Figure 3-2 is a conceptual drawing of a stand-alone multipurpose demonstration article. The configuration is composed of twenty 8 by 8 m bays. Each bay is outfitted with fixtures compatible with a

PROGRAM	OPTION	DESCRIPTION	APPROX COST, $M	OBJECTIVES MET
1	1	BASIC CONSTRUCTION BASE WITH 250 KW SOLAR ARRAY	200 TO 400	29
	2	OPTION 1 PLUS BUILDING OF 100 M RADIOMETER	425 TO 675	33
2	3	BASIC CONSTRUCTION BASE WITH 1 MW SOLAR ARRAY	375 TO 600	34
	4	OPTION 3 PLUS BUILDING OF TRANSMISSION ANTENNA FOR SPS PROOF OF CONCEPT	570 TO 880	37

✓ SELECTED AS BASELINE OCDA PROG (CRITERIA - COST EFFECTIVENESS)

Figure 3-1 OCDA Program Options

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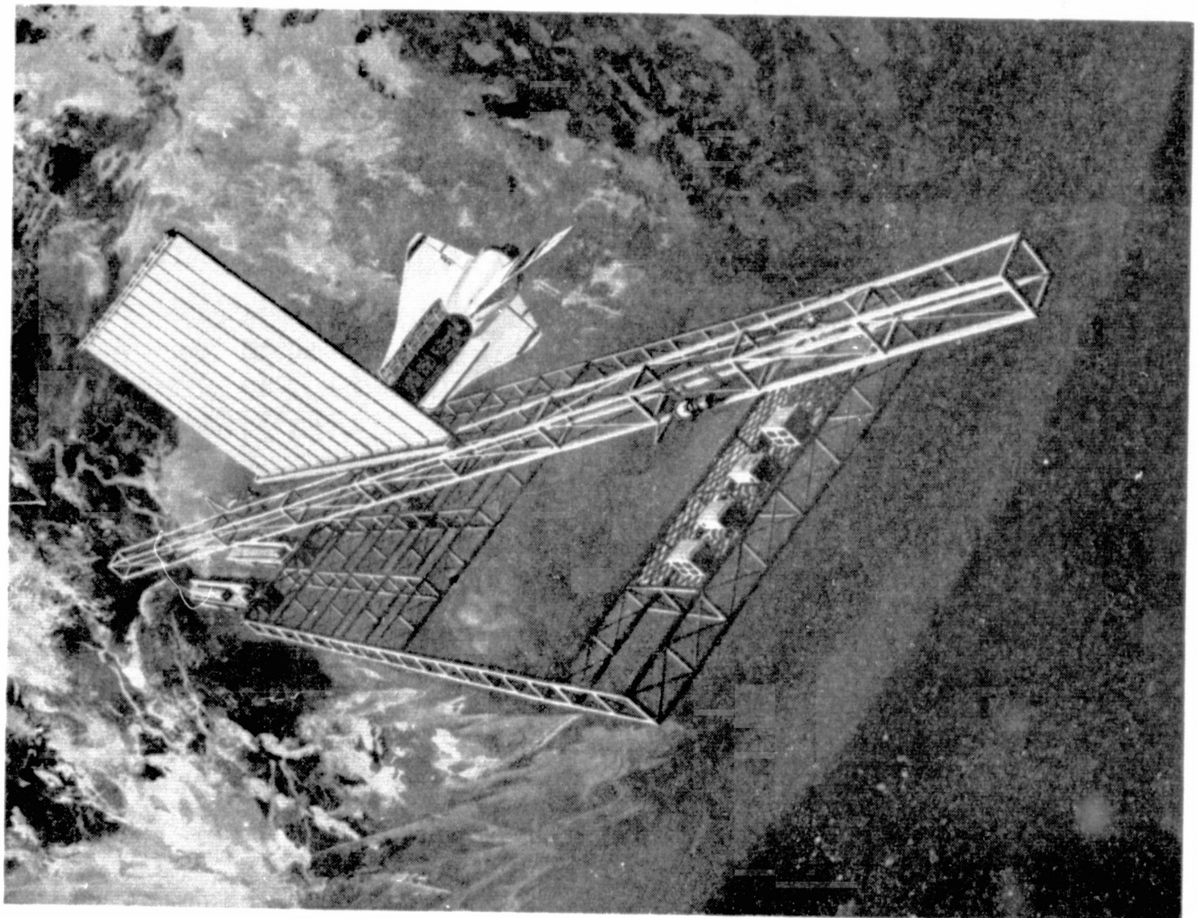


Figure 3-2 Conceptual Rendering of Stand-Alone
Multi-Purpose Demonstration Article

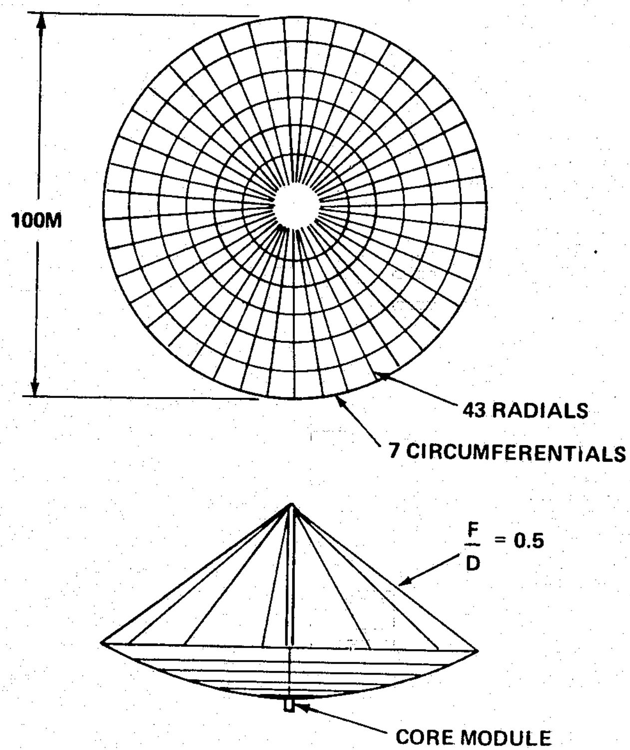
Shuttle pallet of experiments and equipments. A large 24 x 32 m open area is used for demonstrating procedures for mounting solar blankets, thin film mirror surfaces of wire mesh and receiving rectenna mesh. The large area can be enclosed by a safety net for EVA joint and fastener experiments.

A core module contains the article's subsystems including attitude control, stationkeeping, communications and data handling. A Shuttle-compatible core module docking mechanism is included; additional docking mechanisms are mounted to the periphery of the main structure for materials storage pallets.

A 110-m long boom outfitted with a Shuttle manipulator arm transports equipments and materials on the main structure deck and assists in construction of large beams outside the confines of the demonstration article itself.

The 250-kw array is composed of 13 modified SEPS roll-up solar cell blankets. This level was selected after a review of OCDA continued utility experiment requirements descussed in more detail in Section 5. Some of the space fabrication simulation follow-on experiments would require as much as 70 kw average power. Accounting for housekeeping power requirements and efficiency of the power distribution system and energy storage systems, 250 kw is approximately the array size needed to perform these experiments.

The characteristics of a 100 m parabolic antenna for use in earth resource observation as a radiometer and radar are summarized in Figure 3-3. This device is typical of the structure that can be built



ELEMENT	MASS ESTIMATE Kg	MASS ESTIMATE LBM
• ANTENNA	(4130)	(9107)
– SURFACE MESH	200	441
– STRUCTURE		
• CIRCUMFERENTIALS	230	507
• RADIALS	1,900	4,190
– HUB	600	1,323
– BOOM	200	441
– MECHANICAL SYST	1,000	2,205
• SUBSYSTEMS	(935)	(2062)
– STRUCTURE/THERMAL CONTROL	200	441
– ATTITUDE CONT (ACS)	40	88
– COMM	200	441
– ELECT POWER	180	397
– DATA MANG (DM)	315	695
• OCDA		
– BASIC	23,500	51,817
– ADDED JIGS, ETC.	(2,000)	(4,410)
TOTAL	30,565	67,396

Figure 3-3 Option 2— Construction Demonstration Article Used to Construct 100-m Antenna

on the multipurpose construction base (Option 1). The antenna mass was scaled from a device presented in a LaRc final report proposed by Astro Research (ARC-R-1008, "Design Concepts and Parametric Studies of Large Area Structures"). The subsystem mass characteristics are derived from a LaRc document "Benefit/Cost Study of Large Area Space Structure" (Contract NAS1-12436).

The antenna structure utilizes 43 radials and 7 ring (circumferentials) to provide a rf wire mesh surface accuracy of $\lambda/10$. The electronics are mounted at the end of a central mast with a length equal to half the diameter of the antenna. The mast is an "Astromast" providing the capability to partially retract and therefore change the focal length of the antenna. Retractable stays from the mast to the edge of the antenna provide added stiffness and countour control.

Figure 3-4 is a conceptual rendering of the OCDA used as a construction base for the 100 m earth resource antenna (Option 2). A HUB is placed at the corner of the open bay, along with jigs, for holding the radials placed along the edge of the OCDA.

The antenna is constructed by space-fabricating a radial, inserting it into the HUB, fixing the radial to the jig and attaching the circumferentials. The HUB is rotated 8.4°. The next radial is inserted into the HUB and tied to the jig and circumferentials. The mesh is then assembled using the radials and circumferentials as a base. This procedure is repeated until the entire antenna is assembled.

3.1.2 Program 2

A Photovoltaic Solar Power Satellite Demonstration Article, shown conceptually in Figure 3-5, is a "proof-of-concept" of power generation in space and microwave transmission of the power to a ground-based receiving antenna. The array generates 1 Mw of power which is converted to 10 kw at the ground rectenna. The solar array is assembled using SEPS solar blankets modified in length. The con-

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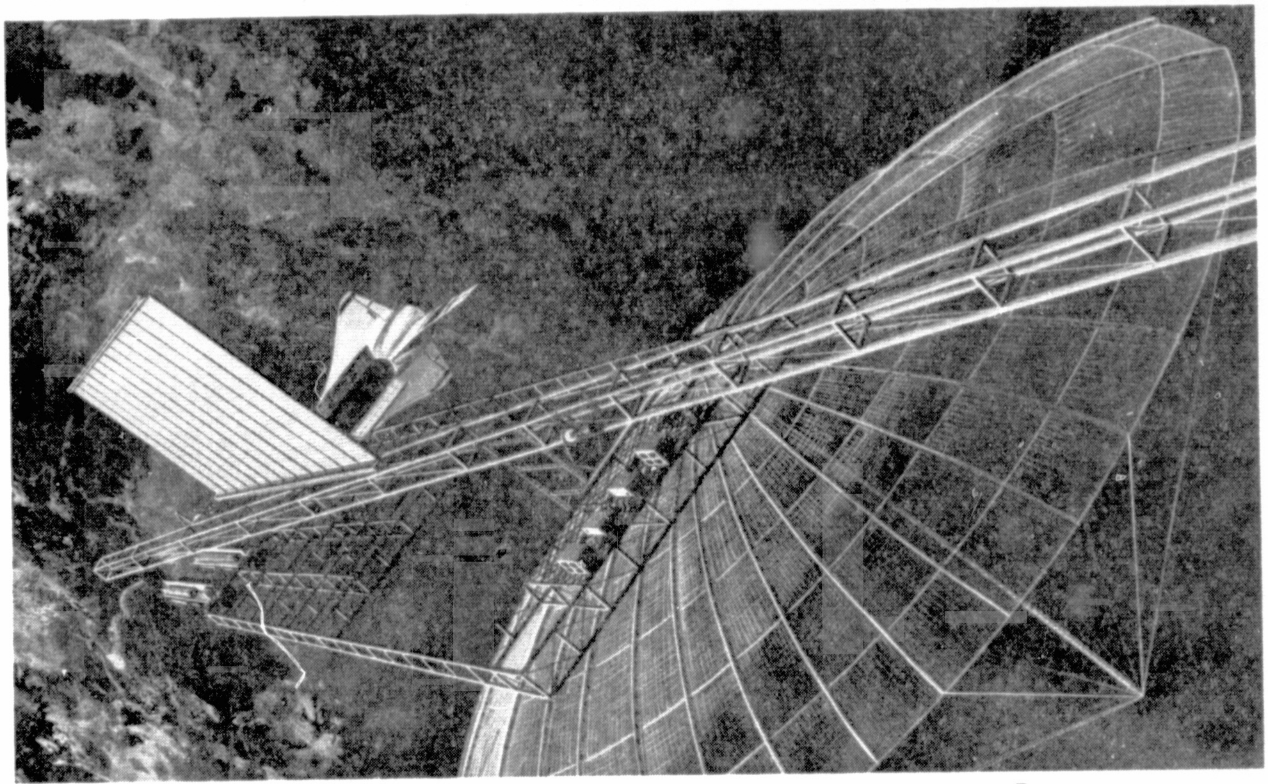
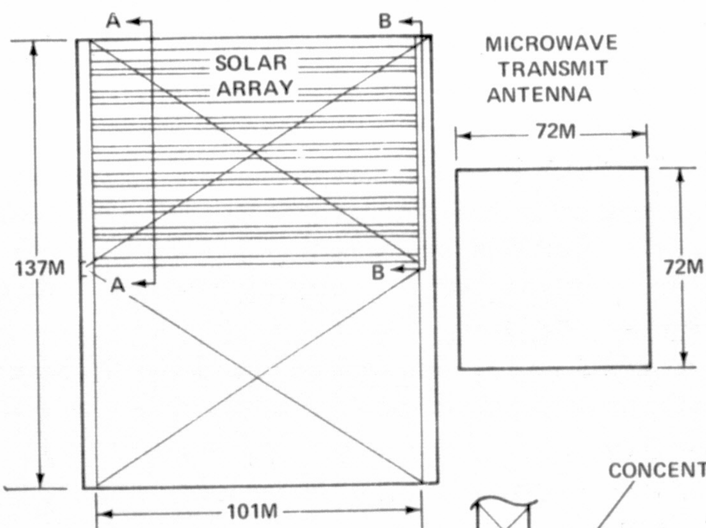


Figure 3-4 Conceptual Rendering of OCDA Used as Construction Base for 100-m Earth Resource Radiometer



MASS		
ELEMENT	Kg	LBM
SOLAR ARRAY	(13,726)	(30,232)
BLANKETS	9685	21333
CONCENTRATORS	553	1219
DEPLOYMENT STRUCT	2724	6000
SUPPORT BEAMS	454	1000
BUS SYSTEM	310	683
TRANSMIT ANTENNA	(13,724)	(30,163)
MW TUBES	972	2141
POWER DISTRIBUTION	887	1954
PHASE CONTROL ELECT	978	2154
WAVEGUIDES	7941	17491
STRUCTURE	1548	3410
CONTOUR CONTROL	1368	3013
ROTARY JOINT	(13,620)	(30,000)
CORE MODULE	(2286)	(5035)
TOTAL	43,366	95,431

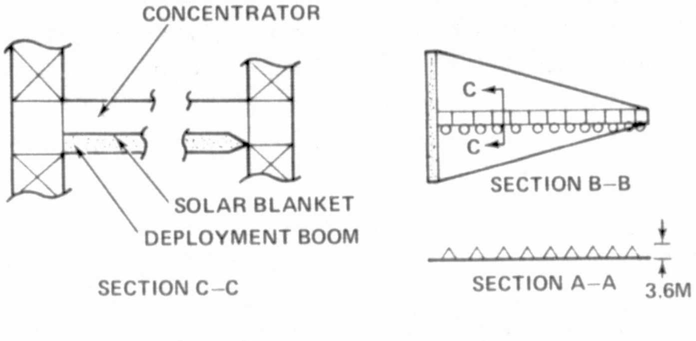


Figure 3-5 Photovoltaic SPS Demonstration

figuration uses mirrors to operate at a concentration ratio of 2. The microwave transmitting antenna has an aperture of 72 m while the ground rectenna has a 100 m dimenstion.

Figure 3-6 presents two relationships used to size the SPS demonstration article. The first shows the relationship between the rectenna efficiency as a function of microwave power input; the second relates dimension of the rectenna to power density on the boresight of the receiving aperture. A rectenna small chip area Si-W element, operating at high impedance and using a Schottky Barrier Junction with low barrier voltage, has the potential to operate at acceptable efficiency levels for a low power level demonstration. Using this rectenna element, it would be possible to generate 10 kw of power using a 100 to 300 m rectenna.

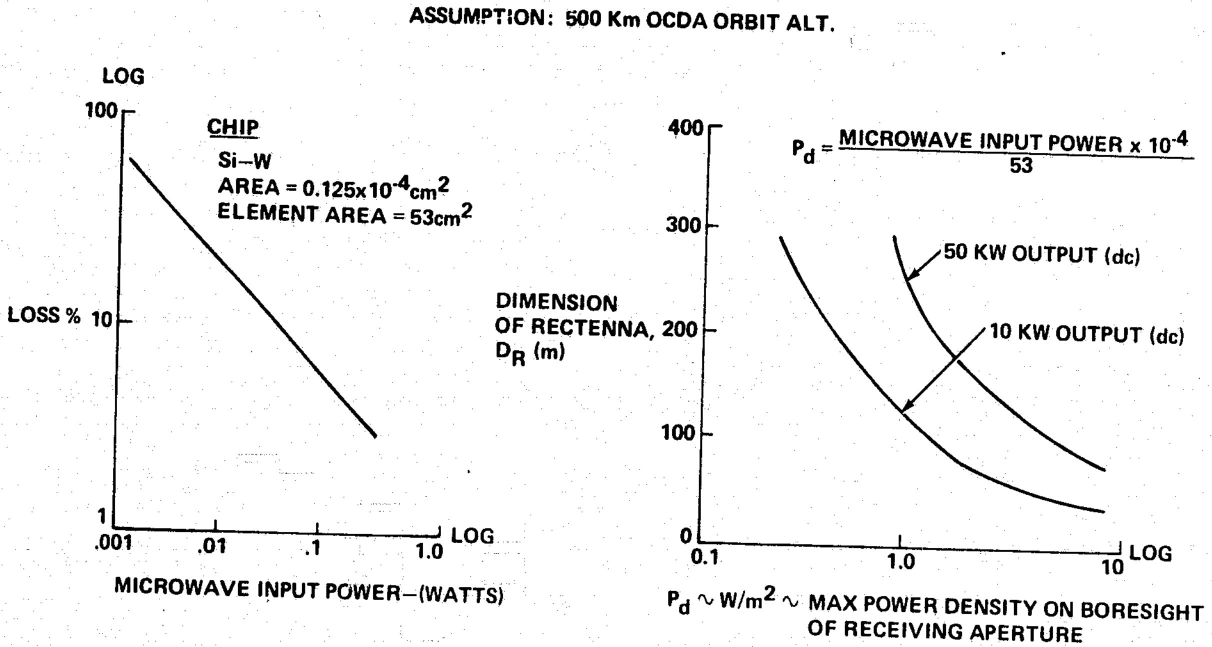


Figure 3-6 Receiving Aperture Dimensions

The relationship between transmitted power and antenna dimensions for two levels of ground output power and rectenna dimension is shown in Figure 3-7. If 10 kw of output power is considered acceptable in terms of demonstrating the feasibility of generating power in space and transmitting the power to ground, a transmitting antenna must be largar than 40 m to avoid excessive support strucutre temperatures.

The configuration selected for further study assumes a 100 x 100 m rectenna with an output power of 10 kw. The smaller rectenna size was selected because the size is more in line with the power output for demonstration value. Based on this rectenna output level, the required transmitted power versus the mass of a solar array needed to generate the power is shown in Figure 3-8. A 1 Mw array was selected based on the potential to deliver the array to the assembly site with one Shuttle launch operating at a 50% load factor.

In this program scenario, initial placment of the OCDA (Option 3) would include the construction platform and supporting rotating boom for construction. The growth version of this base is a SPS proof-of-concept. Option 4, shown in Figure 3-9 utilizes the 1 Mw array to drive the microwave elements of a 72 m aperture antenna. The antenna itself is constructed using the platform as a work area.

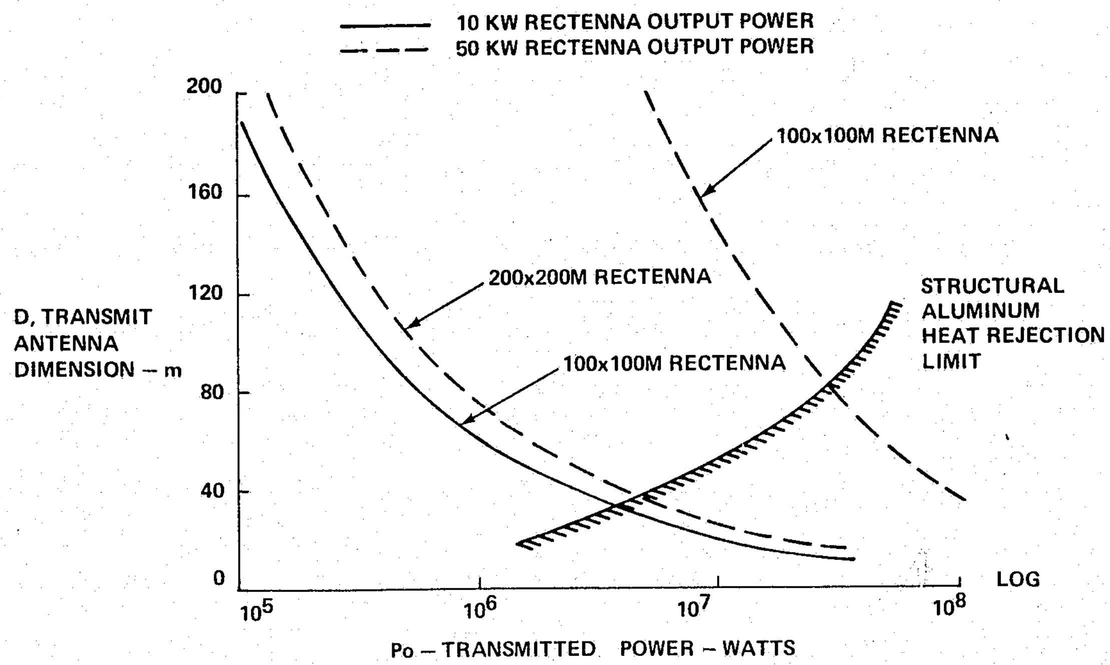


Figure 3-7 Transmit Antenna Dimensions, 500 km OCDA Orbit Altitude

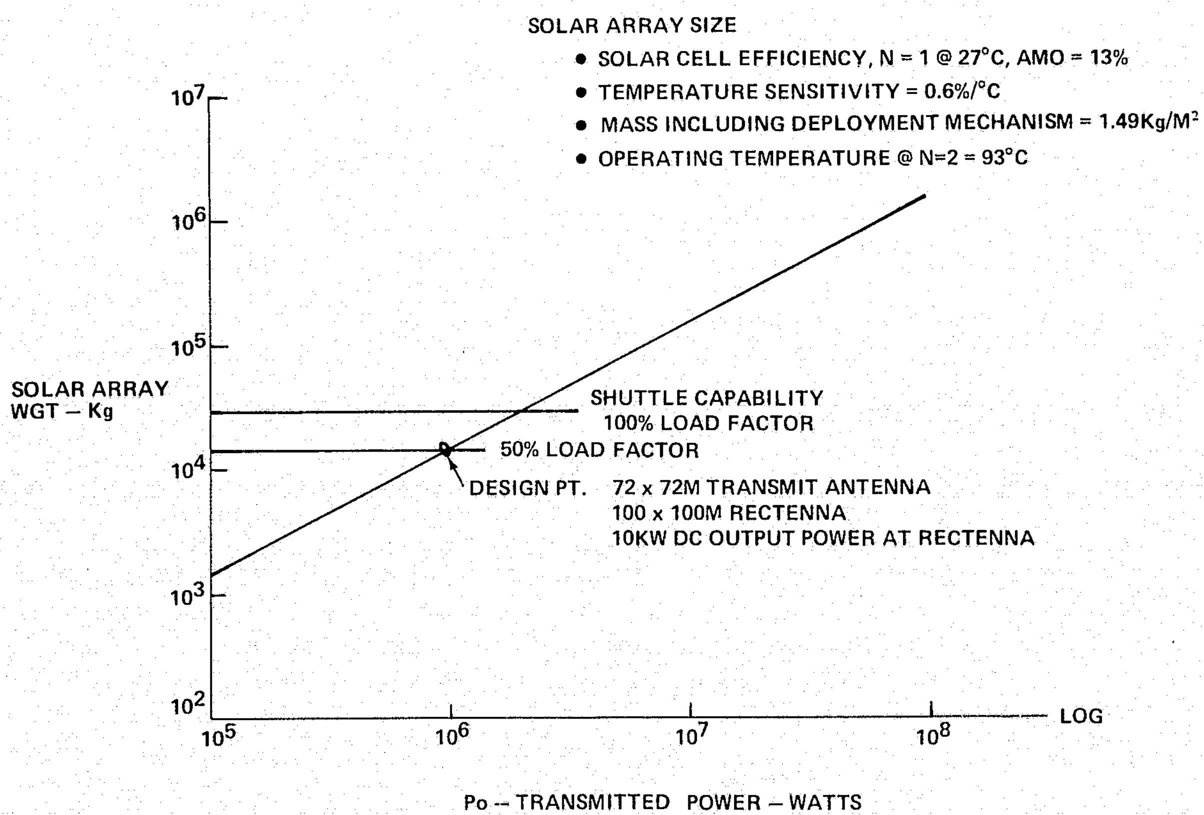


Figure 3-8 Solar Array Size

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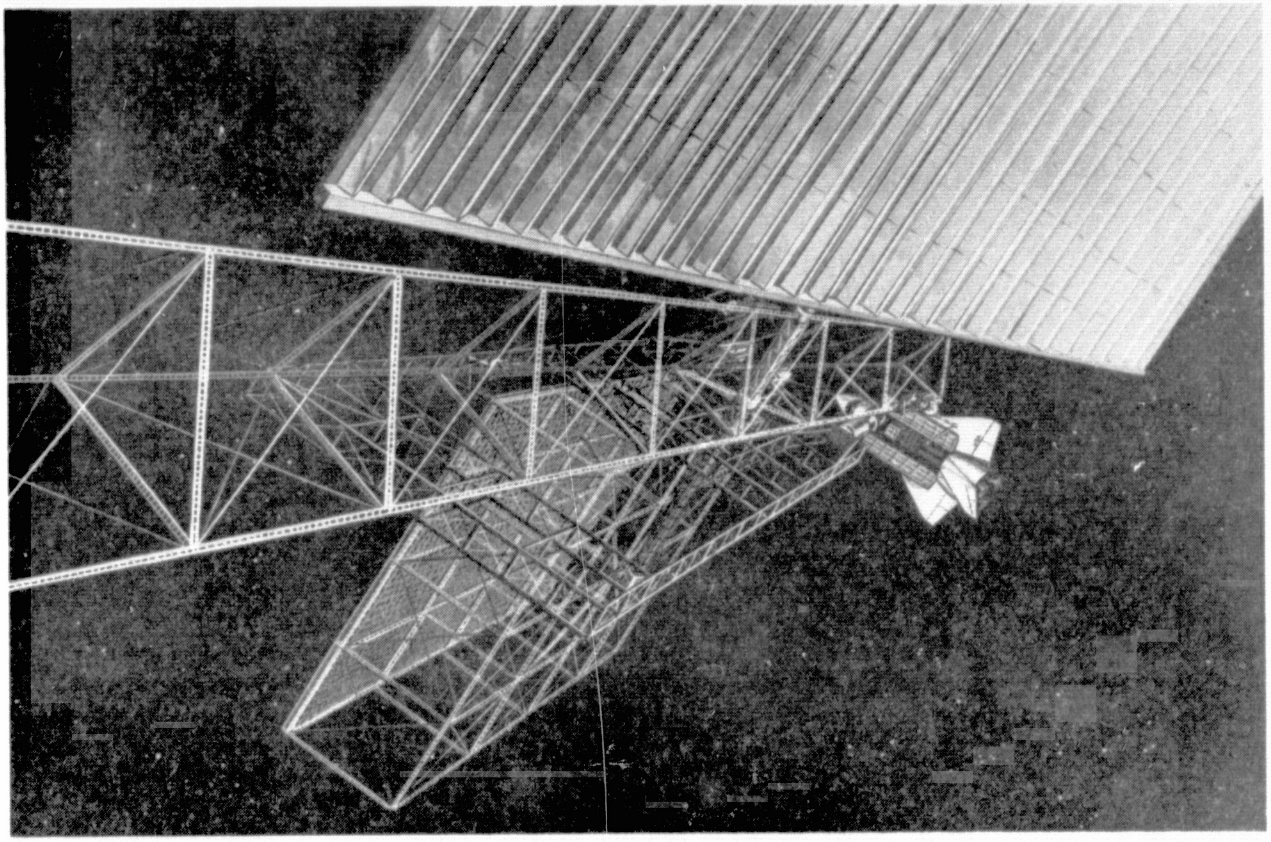


Figure 3-9 Utilization of 1 Mw Array to Drive Microwave Elements of a 72-m Aperture Antenna

3.2 CONCEPT SELECTION

This subsection discusses the OCDA concept evaluation and ranking . The ranking was established using the following four criteria:

Rank	Criteria
1	Mission Suitability (% objectives met on initial OCDA deployment)
2	Cost/Number of Flights for Deployment
3	Continuing Utility Potential
4	State-of-the-Art (Risk)

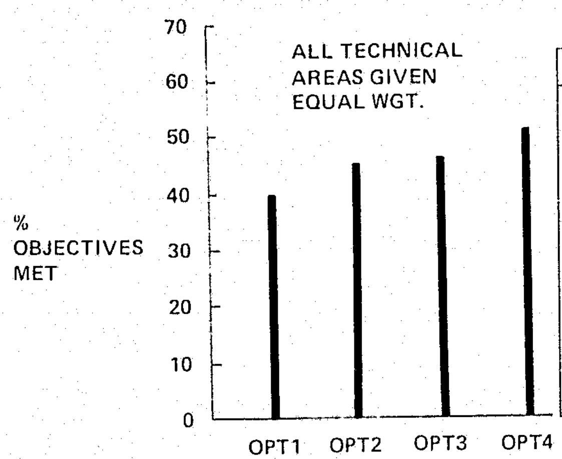
The potential number of demonstration objectives met during initial deployment was rated the highest criteria for selection. Cost and the number of flights needed for initial deployment of the demonstration article was of second importance. The continuing utility potential of the article was ranked third in importance, and the state-of-the-art (or risk) involved with the article's development is fourth.

The figure-of-merit criteria used in the comparison of OCDA options in terms of the demonstration objectives each article can meet is summarized in Figure 3-10. Each demonstration objective identified in the mission analysis effort was ranked as to the value a space demonstration would have in resolving the given problem. A set of mission suitability criteria was then assigned to each OCDA option.

Figure 3-11 summarizes the figure-of-merit mission suitability of each OCDA option. Option 4 is ranked the highest while Option 1 is ranked the lowest. The difference between options in terms

	MISSION SUITABILITY FOR MEETING OBJECTIVES				
	1 2	3 4	5 6	7 8	9 10
OCDA DEMO INPUT TO CONFIDENCE LEVEL FOR DECISION	• LITTLE OR NO VALUE	• PARTIAL DATA INPUT PROVIDED IN INITIAL DEPLOYMENT. NEED HIGH DEGREE OF FOLLOW ON ADDED EXPERIMENTS TO MEET OBJECTIVES	• PARTIAL DATA INPUT PROVIDED DEPLOYMENT. MODERATE FOLLOW-ON ADDED EXPERIMENTS NEEDED TO MEET OBJECTIVES	• HIGH LEVEL DATA INPUT IN INITIAL DEPLOYMENT. LIMITED FOLLOW-ON ADDED EXPER NEEDED TO MEET OBJECTIVES	• HIGH LEVEL DATA INPUT IN INITIAL DEPLOYMENT. ADDED EXPERIMENTS DESIRABLE BUT NOT MANDITORY TO MEETING OBJECTIVES

Figure 3-10 OCDA Mission Suitability Criteria



	% OBJECTIVES MET			
	PROGRAM 1		PROGRAM 2	
TECH. AREA	OPT 1	OPT 2	OPT 3	OPT 4
• STRUCTURE	35	47	51	56
• POWER DISTRIBUTION	39	39	50	60
• SOLAR ARRAY	34	34	41	41
• PROPULSION	50	50	50	50
• TRANSMISSION	22	22	22	53
• STABILIZATION	60	60	70	80
• RF REFLECTORS	30	90	30	30
• MIRRORS	40	40	50	50
• RADIATORS	40	40	50	50
• THERMAL CAVITIES	30	30	30	30

Figure 3-11 Figure of Merit Mission Suitability Comparison

of figure-of-merit percentage of objectives met is not so great as to single out any one option as a clear leader. The major reason why all options did not score high (80 to 90%) in mission suitability was the criteria that weighed the ability to meet the given objective in the initial deployment of the article. A second reason for low score is a scale uncertainty which produced a reluctance on the part of the assessment team to assign a high percentage mission suitability to OCDA's that are small relative to the future mission configuration.

A cost comparison of the four ODCA options is shown on Figure 3-12. Cost ranges are given for DDT&E, first unit and the number of Shuttle flights required to deploy and construct the article. The following groundrules were used in these estimates:

- Cost in 1977 constant dollars
- Cost data excludes crew equipments and orbital construction facilities/equipments
- Core vehicle will consist of 75% off-the-shelf NASA standardized spacecraft subsystem moduels
- Solar array development cost are the same as that for SEPS program.

	SHUTTLE FLIGHTS			
	PROGRAM 1		PROGRAM 2	
HI EST.	5	6	7	12
LOW EST.	2	2	2	4

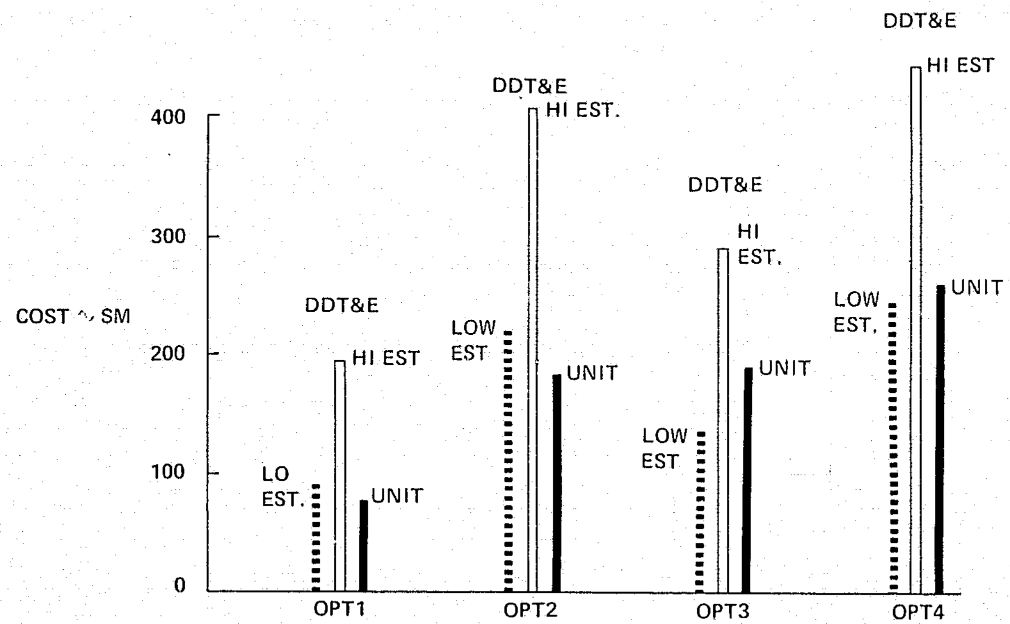


Figure 3-12 Concept Cost Comparison

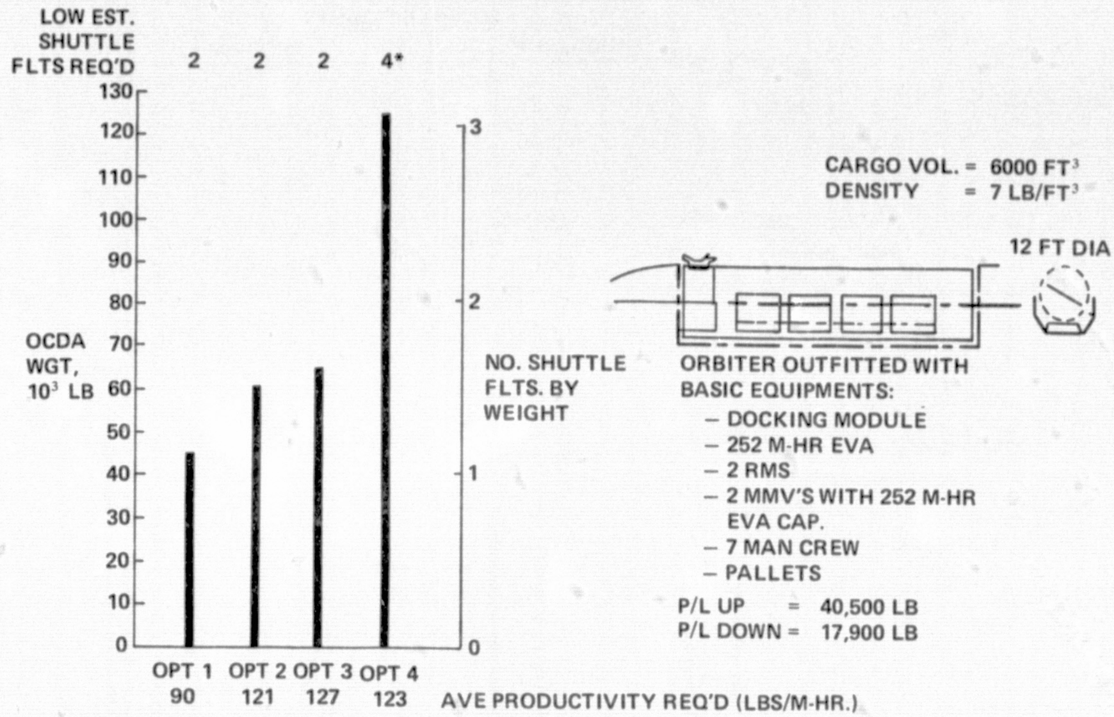
The initial total cost estimates are as follows:

- Option 1: \$189 to \$337 million
- Option 2: \$424 to \$668 million
- Option 3: \$369 to \$587 million
- Option 4: \$563 to \$879 million

assuming \$14.5 million per Shuttle flight.

The information used to establish the lower limit of flights required for deployment are summarized in Figure 3-13. The Shuttle was assumed configured for a 7-man crew, and carries a docking module and four pallets. A second RMS was added and consumables for 252 manhours of EVA capability added to the inventory. Two Manned Maneuvering Units (MMU's) were included with sufficient propellant for 252 manhours of operation. The payload capability with these equipments were 40,500 lb (18,387 Kg) up and 17,900 lb (8,127 Kg) down. A cargo volume of 6000 cu ft (170 m^3) was available. Under the assumption that deployment and construction techniques will bring assembly cost within the standards for terrestrial mass-produced products, a productivity of between 12 and 40 lb/manhour (5.4 and 18 Kg/manhour) was assumed reasonable for purposes of preliminary estimates of Shuttle flights required. It was assumed that 252 manhours per flight would be available for construction duties. Using these assumptions for mass and construction time, Options 1 through 4 could be assembled in the required six flight limit.

Option 1 (Figure 3-14) was selected for concept definition in Tasks 2 through 5. The 250-kw array or smaller was judged adequate to meet near-term construction demonstration objectives with Shuttle revisits to the OCDA. Costs for Option 1 were considered modest for a program of this type. The low



*NOTE: THIS OPTION REQUIRES ONLY 2 ADDITIONAL FLTS AFTER OPTION 3 IS CONSTRUCTED.

Figure 3-13 Shuttle Flights Required by Weight

		PROGRAM 1		PROGRAM 2	
CRITERIA		OPT 1	OPT 2	OPT 3	OPT 4
MISSION SUITABILITY (%)		40	45	47	51
COST	DDT & E ($M)	90 TO 195	205 TO 400	150 TO 295	250 TO 450
	UNIT ($M)	70	180	195	260
	FLTS	2 TO 5	2 TO 6	2 TO 7	4 TO 12
CONTINUING UTILITY POTENTIAL		GOOD	VERY GOOD	EXCEL.	EXCEL.
STATE-OF-ART. (RISK)		LOW	HIGH	MODERATE	HIGH

SELECTED FOR CONCEPT DEFINITION STUDY

- 250KW ARRAY IS SUFFICIENT TO MEET NEAR TERM MODEST CONSTRUCTION DEMO OBJECTIVES
- COST IN LINE WITH BUDGETS
- RISK IN LINE WITH IOC

Figure 3-14 Concept Comparison

risk of equipments was also a factor. The major risk factor for Option 1 was then contained to the actual assembly operations themselves and not the hardware.

3.3 DESIGN REQUIREMENTS

A series of OCDA follow-on experiment concept studies were performed to determine the sizing factors for the platform, boom and solar array. The work platform was sized to facilitate construction of 100 m antenna and a large solar array. More details of these experiments are discussed in Section 5. The rotating boom was sized to provide manipulator access to all points on the platform. The solar array was sized to provide continuous 70 kw power to the construction experiments, over and above the 10 kw (average) required for OCDA housekeeping and construction support functions, and 25 kw (average) for Shuttle support.

The work platform was sized at 72 m by 32 m. The 72 m length was selected based on the future (follow-on) mission desire to build 100 m diameter antennas for radiometry and communications. A minimum of 50 m is required to build the antenna, and approximately 20 m was judged necessary to house the core module, power mast, etc. The 32-m width was selected based on initial construction requirements. The Shuttle-based Remote Manipulator System (RMS) reach constrains the platform width to 32 m if the back edge set of the platform structural cubes are to be constructed with assistance from the Orbiter.

The OCDA power requirements vary considerably from the very low value of approximately 10 kw needed for housekeeping between orbiter visits, to that required by experiments. The experiments evaluated for purposes of selecting the ODCA power level are listed in Figure 3-15. The power requirements needed to simulate mass production of segments of the ultimate SPS were used for basic sizing of 250 kw. Other potential uses of 250 kw are indicated in the figure. A recent recommendation by Raytheon for testing the phase control electronics of a linear power transmitting array would be within the capability of the OCDA.

3.3.1 Flight Mechanics and Control

Studies were performed to determine OCDA attitude control and orbitkeeping requirements. These studies, performed as part of Task 5 (see Figure 1-2), were needed to assess the technical feasibility of the concept and to provide basic design data for solar array, control system and structural sizing.

EXPERIMENT	LOAD POWER	ARRAY POWER
1. SIMULATED MASS PRODUCTION OF LARGE STRUCTURES	20 TO 64 KW	64 KW TO 210 KW
2. LINEAR WAVEGUIDE		
• 100M LONG, FULL MPTS RANGE OF POWER DENSITY	100 TO 200 KW	140 TO 280 KW
3. DC-TO-RF CONVERSION IN STEPS (18 X 18m SUBARRAY)		
• 1/3 POWER FOR 10 DB SUBARRAY	250 TO 300 KW	350 TO 420 KW
• FULL POWER FOR 10 DB SUBARRAY	700 TO 900 KW	980 TO 1260 KW
• 1/3 POWER FOR 5 DB SUBARRAY	800 TO 1000 KW	1120 TO 1400 KW
• FULL POWER FOR 5 DB SUBARRAY	2.5 TO 3 MW	3.5 TO 4.2 MW
• 1/3 POWER FOR 0 DB SUBARRAY	2.5 TO 3 MW	3.5 TO 4.2 MW
• FULL POWER FOR 0 DB SUBARRAY	8 TO 9 MW	11.2 TO 12.6 MW
4. DEMO TRANSMISSION TO GROUND	1 TO 10 MW	1.4 TO 14 MW

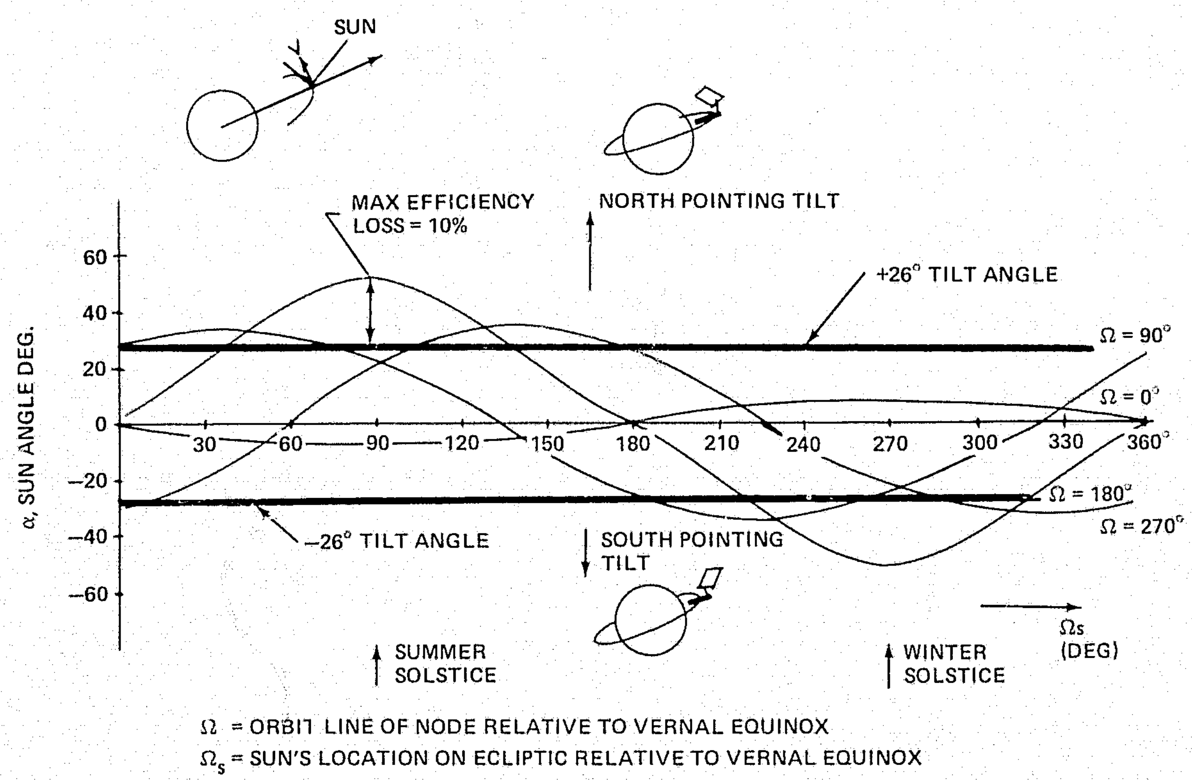
Figure 3-15 Experiment Power Requirements

The yearly variations of the sun relative to the solar array was evaluated to determine the need and approach for array steering. The relative orientattion of the orbit plane with respect to the ecliptic plane is described by the angle Ω_S which varies over the year as shown in Figure 3-16. The possible sun angles are described by the total area between the set of curves representing the full range of angles for the line of nodes relative to the vernal equinox. A pitch-oriented array with its plane perpendicular to the orbit plane would experience up to a 38% reduction in efficiency. Tilting the array plus or minus 26°, as required, reduces the maximum efficiency loss to 10%. An evaluation of the orbit time history shows that the solar array tilt will be changed every 22 days due to the effects of orbit nodal regression.

The configuration-dependent factors which were considered in the development of the attitude control requirements include:

- Inertia and disturbance torgue effects of the tilted, rotating solar array
- Drag and inertia effects of a fully and partially deployed array.
- Construction boom position
- Potential experiments, including some which significantly change mass distribution
- Special orientation requirements of some experiments which may require slewing away from the nominal earth-oriented attitude for periods of time
- Inertia, geometry and orientation characteristics during OCDA buildup.

The major impacts were found to be caused by the tilted, rotating array and the effect of the orbiter mass which change the inertias, moment arms and disturbance torques.

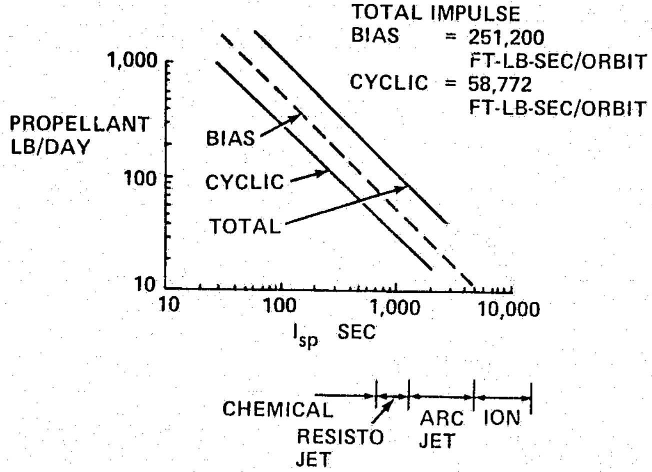


YEARLY VARIATIONS OF SUN ANGLE

Figure 3-16 Solar Array Test Angle Requirements

The primary disturbance torque sources are aerodynamic drag and gravity gradient. The gravity gradient torques, shown in Figure 3-17, include the effect of the sun-tracking, tilted solar array which results in a cyclic disturbance. The Orbiter was also shown to have a significant effect, especially on the x-axis, shifting the principal axes approximately 15° from the control axes. The disturbance torques were divided into a constant (unidirectional) bias term and a cyclic term with a frequency of orbital rate. The dominant aero torque was due to the rotating solar array which causes equally large cyclic and bias terms. A drag coefficient (C_D) of 2 was assumed for the solar array and orbiter, and 2.5 was used for the boom and platform corresponding to open beams with cavities.

	TORQUES (FT-LBS)											
	WITH ORBITER						WITHOUT ORBITER					
	T_x		T_y		T_z		T_x		T_y		T_z	
	BIAS	CYCLIC	BIAS	CYCLIC	BIAS	CYCLIC	BIAS	CYCLIC	BIAS	CYCLIC	BIAS	CYCLIC
AERODYNAMIC	0	0	- 5.5	±4.8	21.5	±20.2	-0	0	8.5	± 8.7	12.0	±12.3
GRAVITY GRADIENT	9.0	±5.6	- 8.0	±1.6	1.5	± 0.5	-9.0	±3.5	-2.0	± 2.2	- 1.0	± 0.6
SOLAR PRESSURE	0	±0.4	0	0	0	± 0.4	0	±0.3	0	0	0	± 0.3
MAGNETIC (UNCOMP)	0.02	0	0	0	0.02	0	0.003	0	0	0	0.003	0
TOTALS	9.0	±6.0	-13.5	±6.4	23.0	±21.1	-9.0	±3.8	6.5	±10.9	11.0	±13.2



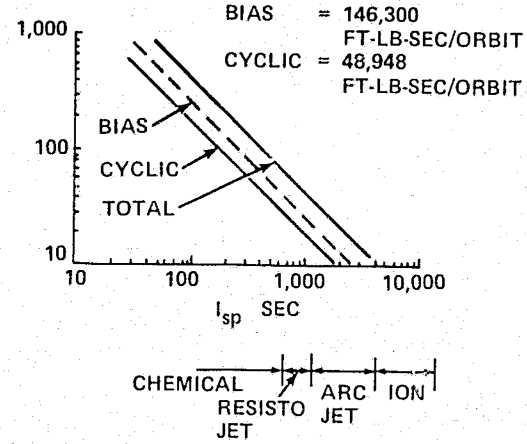


Figure 3-17 Control System Requirements

Assuming that under worst-case conditions, the cyclic terms were all in phase, the total bias and cyclic torques were added resulting in a conservative estimate for the total cyclic torque. The cyclic torque impulse values on a half cycle basis indicate sizable angular momentum requirements. This results in unnecessary propellant consumption which can be alleviated by using momentum storage devices.

The effect of aerodynamic drag at 190 n mi (352 km) on the OCDA, shown in Figure 3-18, was determined by estimating the ballistic coefficient of each major section individually. A drag coefficient of 2 was used for the solar array, mast and shuttle, and 2.5 for the boom and platform. An effective drag area of 60% of maximum was assumed for the array. The array was by far the dominant effect, resulting in a drag force of approximatley 0.3 lb opposing the orbited velocity. This would require about 1,600 lb (720 kg) of propellant per year using an argon ion thruster with an I_{SP} of 6,000 sec.

The Space Transportation System (STS) capability for delivering cargo to circular orbits as a function of orbit altitude is shown in Figure 3-19, including rendezvous capability with no OMS kits. The

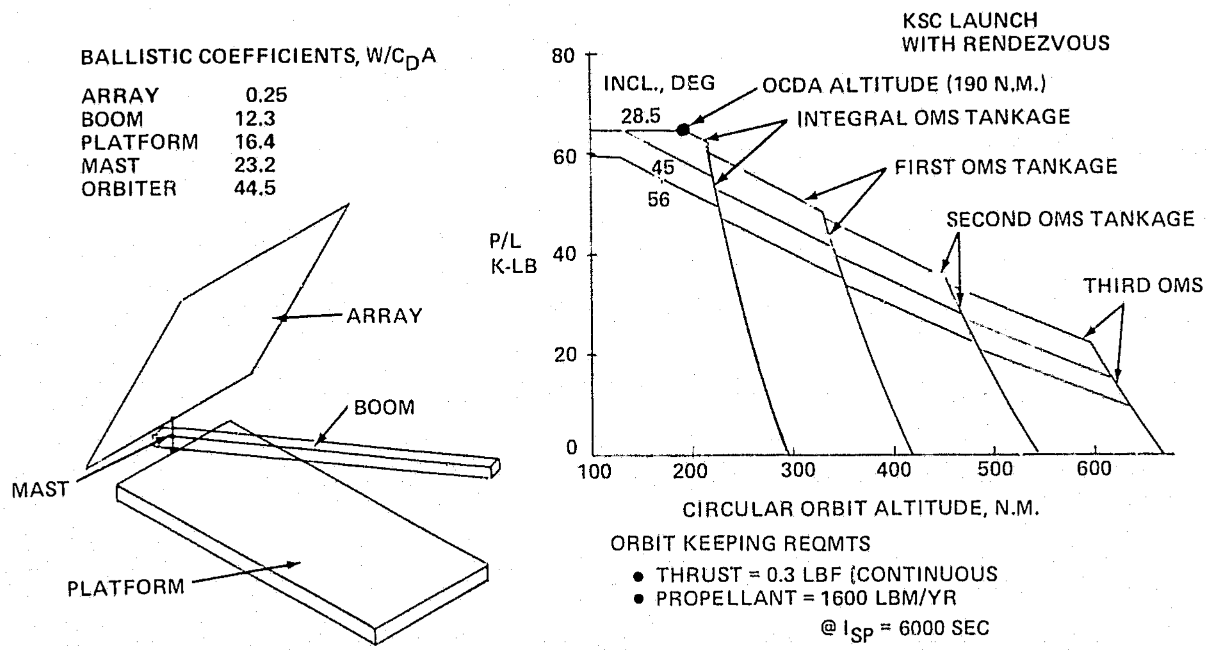


Figure 3-18 Orbitkeeping Requirements

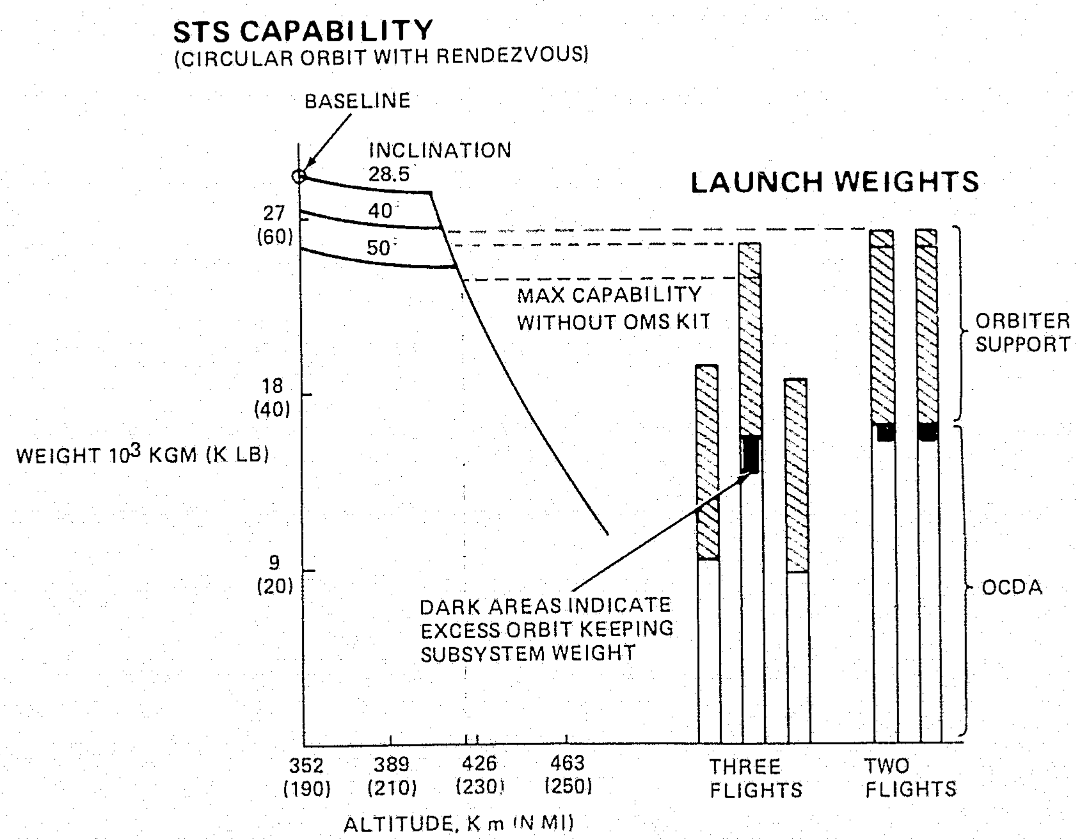
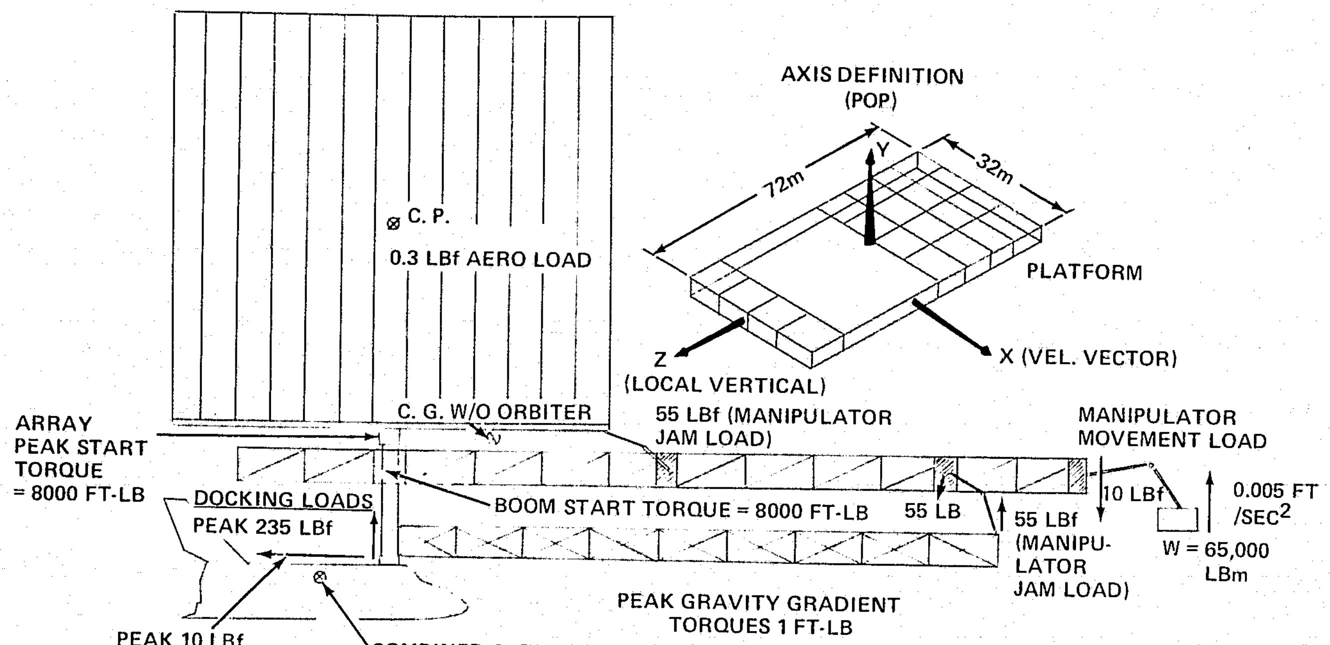


Figure 3-19 OCDA Launch Tradeoff

effect of orbit inclination vanishes above about 227 n mi (420 km) over the inclination range 28.5°. The launch weight for the three flights required for OCDA construction (see Section4) indicate the ability to attain an altitude of about 227 n mi (420 km) even for a 50° inclination when the reduced orbitkeeping subsystem weight at higher altitudes is considered.

3.3.2 Structural Design Requirements

Structural design loads for the OCDA are summarized in Figure 3-20. Loads due to aerodynamics and gravity gradient are given for the vehicle in a 190 n mi (352 km) orbit. From these loads, two conditions (docking and manipulator jam) were judged most critical and were investigated further. Manipulato jam produces the most critical sizing load. However, stiffness requirement for control system stability is yet to be determined and is the subject of in-house study efforts.



AXIS	W/O ORBITER	WITH ORBITER
X	5.0	8.7
Y	-5.2	-9.4
Z	0.9	1.6

Figure 3-20 OCDA Structure Design Conditions

Preliminary docking loads were calculated for the Shuttle Orbiter docking to the OCDA. Closing velocities of 0.5 fps (0.15 mps) axial and 0.1 fps (0.04 mps) lateral were used in combination with a constant force attenuator with a 1-ft stroke to obtain interface loads. The resulting interface loads were increased by a factor of two to account for actuator nonlinearities and design the limit loads of 235-lb (1045 N) axial, and 10-lb (44.5 N) lateral.

The Shuttle manipulator is capable of producing a 55-lb (244 N) force. Bending moments of 14,800 ft-lb (20,080 N·m) on the boom and 13,000 ft-lb (17,637 N·m) on the platform result if this load is applied at the platform extremities. A torsion load of 2890 ft-lb (3921 N·m) will be induced on the plat-

form when the manipulator load is applied at the outboard edge. To account for the situation where the manipulator jams and suddenly releases, a magnification factor of 2 was applied to these loads for purposes of structureal sizing.

To determine the OCDA platform internal loads, static deflections and required pretention values for diagonals, a finite element model of the OCDA structure was established and COMAP-ASTRAL analyses of the required conditions was made. Initially the structure was modeled in three sections, platform, boom and solar array.

The platform model has 106 nodes, 502 members and 348 degrees of freedom. The most severe loading condition has been shown to be a manipulator jam load at the extreme end of the platform. These conditions cause a platofrm deflection of 55.7 cm (21.93 in.) for an ultimate load of 367 Newtons (82.5 lb) and a boom deflection of 14.2 cm (5.6 in.). It may become necessary to tie down the boom to the platform with rigid temporary structure. The area of the boom corner caps (longitudinals) was determined by the requirements to constrain the manipulator carriage rather then the boom bending requirements. The solar array was modeled with a continuous lower beam which in turn was connected to the core module mast. The upper ends of the astromast had beams in the plane of the array that were pinned at the midpoint between each astromast. The array blankets were represented as a preloaded bar (that acts like a string) between the top and bottom beams. The prime function of this model was to investigate required blanket tension and mast inertia to meet frequency requirements of 0.04 Hz.

The three models were combined to give one model of the total structure with 1046 members and 1378 degrees of freedom. This model is being used to determine the influence coefficients on the dynamic model which will be used to find modes and frequency of the structure. The finite element models will also be used to determine deflections and internal loads for thermal gradients on the structure.

3.4 DESIGN DEFINITION

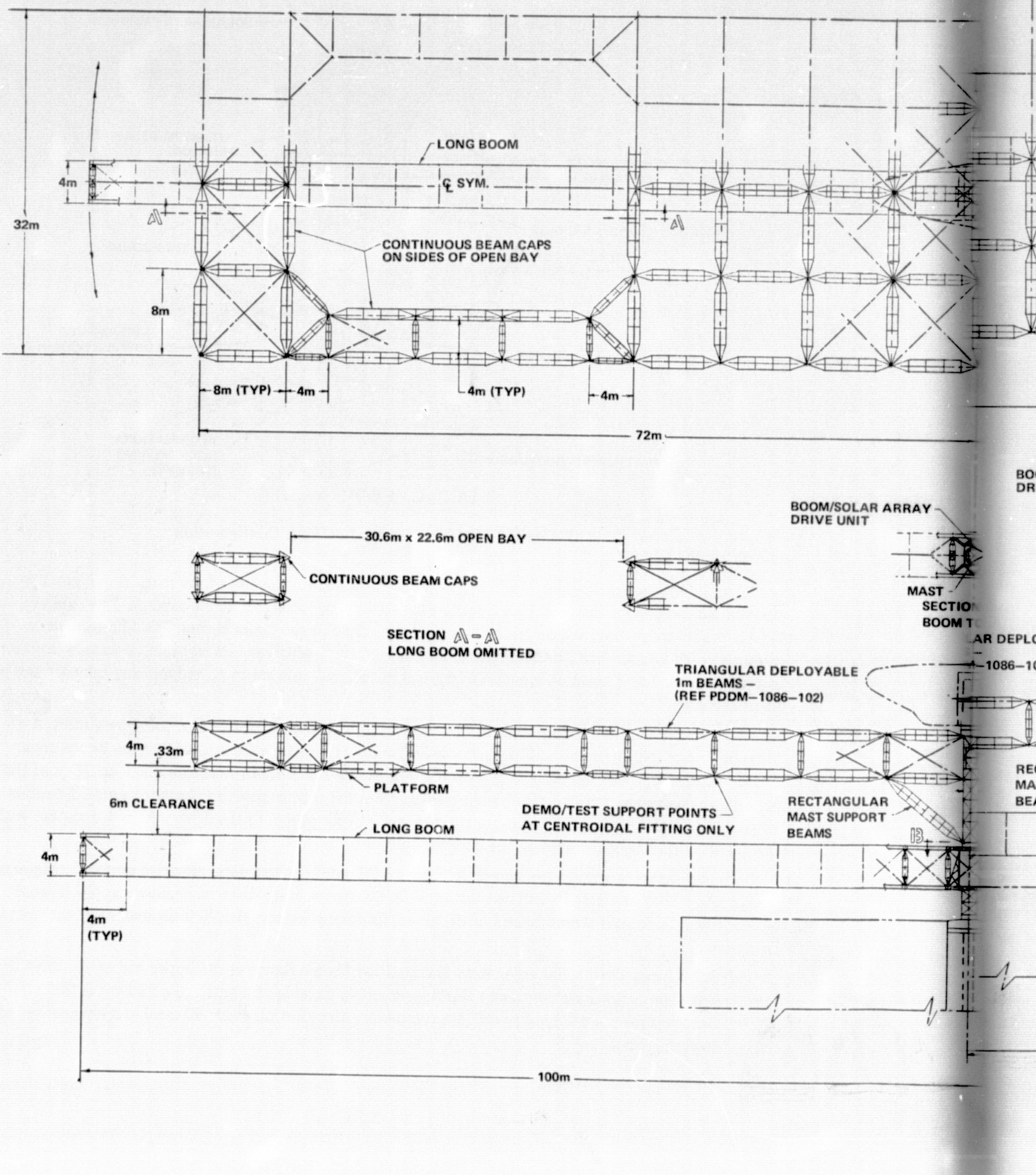
3.4.1 Configuration

The structural arrangement, shown in Figure 3-21, consists of four major assemblies:

- Platform
- Solar Array
- Mast
- Rotating boom.

3.4.1.1 Platform - The platform utilizes deployable tringualr section members with centroidal end fittings (nodals), configured to form rectangular prisms. The 8-m length of the members was shosen to provide efficient stowage within the Shuttle cargo bay. The use of centroidal fittings allows determinate load paths and provides tiedown points on the surface of the platform for mounting experiments. Tubular post with built-in toe holes or hard points for the construction crew are used between the surface of the platform. Diagonal bracing is used to rigidize the bays and provide shear and torsional stiffness to the structure. A large open bay is provided with surrounding structure arranged to provide a continuous edge upon which solar blanket and reflector attachment bungees could be fastened. Trusses stabilize the cargo module docking ring and carry the loads into the edge of the platform structure.

3.4.1.2 Core Module/Mast - The central mast shown in Figure 3-22 consists of 1.4 m square open truss structure, 10.5-m long. It is structurally connected to the platfrom at three levels, each level contains six shear pin attachment points, which provide the shear, bending, and torsional load path between the platform and long boom/solar array.


LONG BOOM
℄ SYM.
4m
32m
8m
CONTINUOUS BEAM CAPS
ON SIDES OF OPEN BAY
8m (TYP)
4m
4m (TYP)
4m
72m
30.6m x 22.6m OPEN BAY
CONTINUOUS BEAM CAPS
SECTION A-A
LONG BOOM OMITTED
BOOM/SOLAR ARRAY
DRIVE UNIT
MAST
SECTIO
BOOM T
AR DEPL
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BO
DR
TRIANGULAR DEPLOYABLE
1m BEAMS –
(REF PDDM–1086–102)
4m
.33m
PLATFORM
6m CLEARANCE
DEMO/TEST SUPPORT POINTS
AT CENTROIDAL FITTING ONLY
RECTANGULAR
MAST SUPPORT
BEAMS
LONG BOOM
4m
4m
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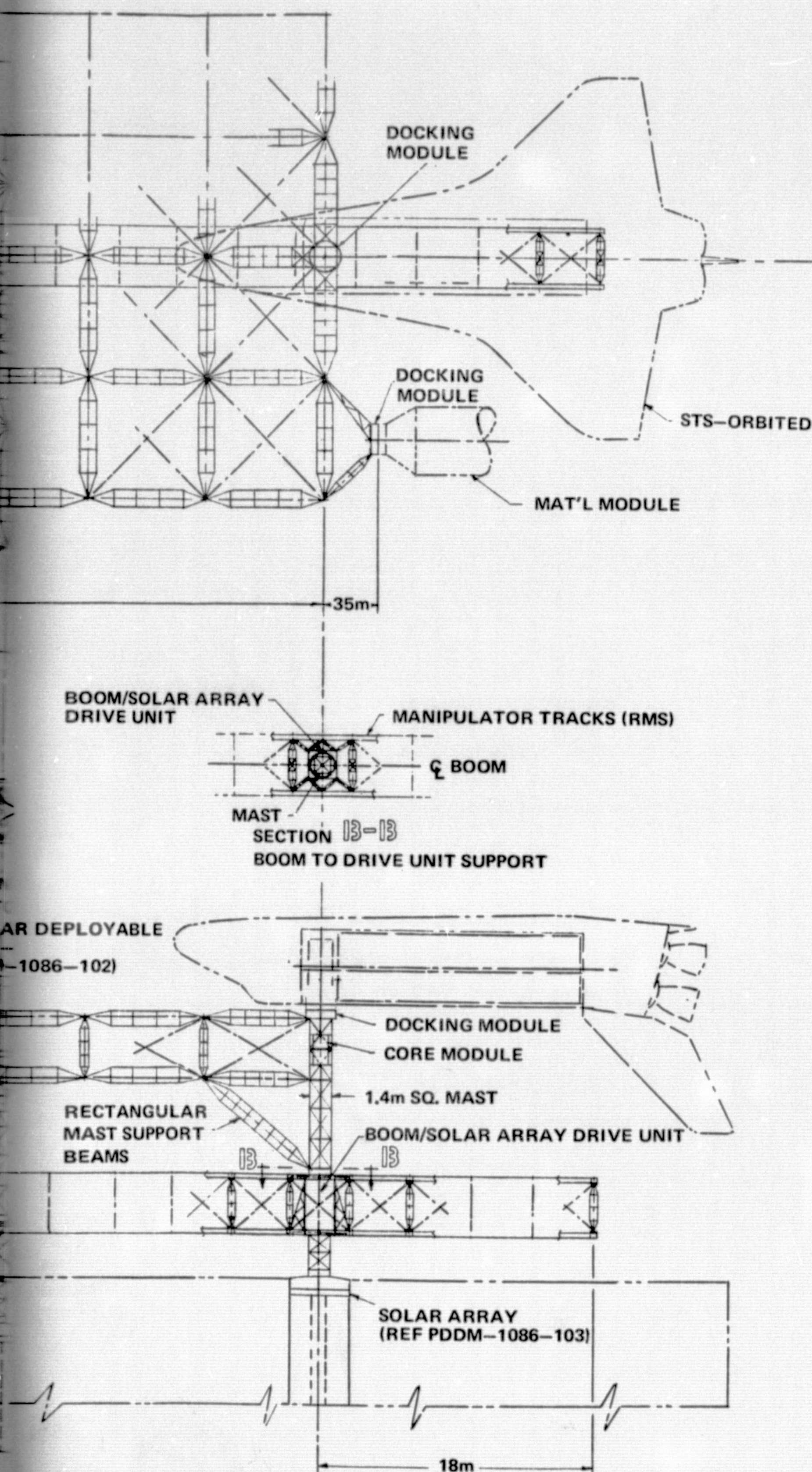

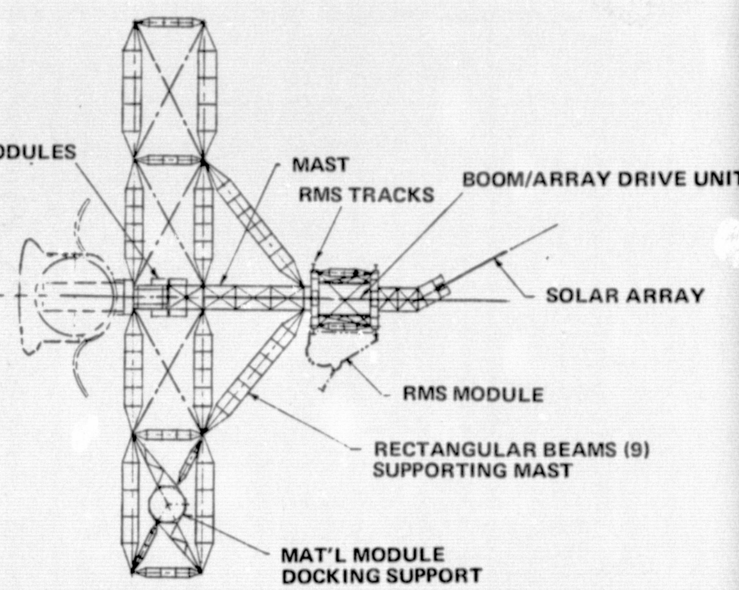

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Figure 3-21 OCDA Structural Arrangements

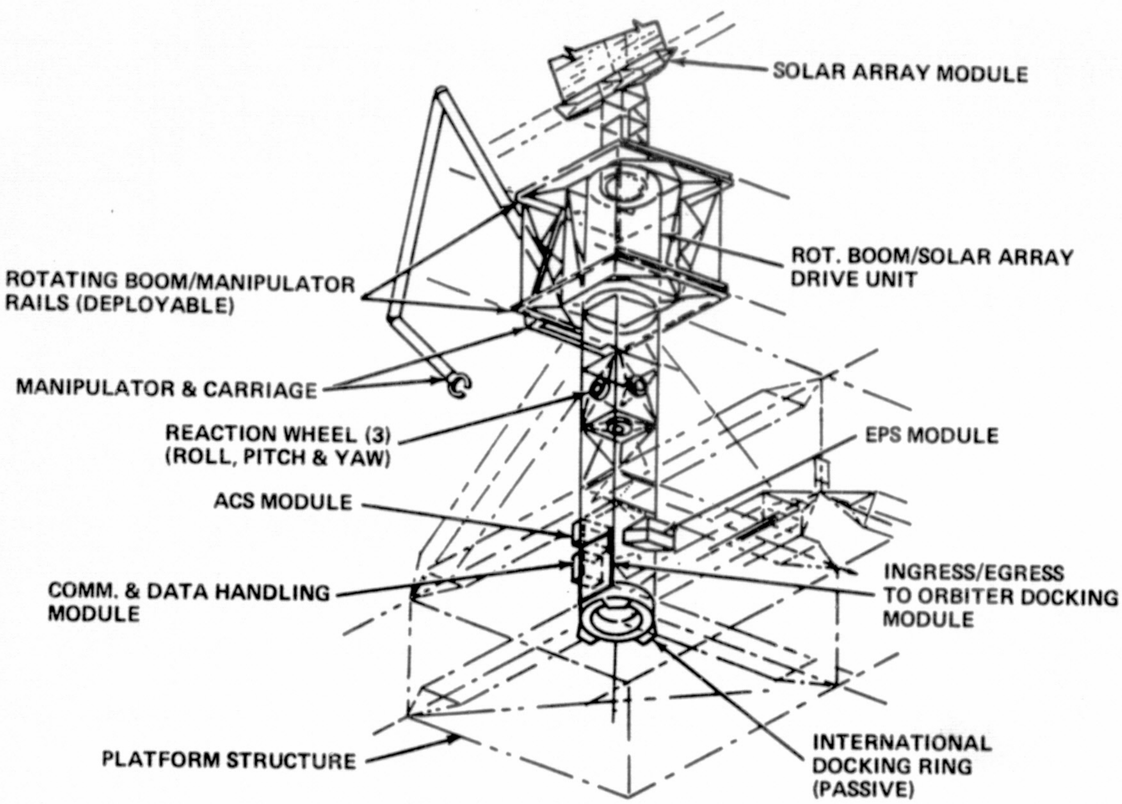


Figure 3-22 OCDA Core Module/Mast Configuration

The International Docking Module (Passive) is mounted on the end of the mast. A 1.2 m x 2 m opening on the face of the mast provides ingress/egress to the orbiter docking module. The ACS and C&DH modules are mounted on the side of the mast, close to the docking ring. The EPS module is mounted with a shade box on the opposite side in a position which shades its radiator surface from direct rays of the sun. Three reaction wheels (ACS), roll, pitch, and yaw are mounted midway between the platform and boom.

The boom/solar array drive unit is mounted on four fittings on the end of the square mast. A deployable 3.5-m length of the RMS rails/boom and support structure are attached to the boom drive. The docking ring, mast and drive unit with the deployable RMS/boom structure make up 15 m of the core module which is pre-assembled and removed from the orbiter payload bay as one unit. The solar array modules and its support structure are attached at four points to the drive unit and, together with the 15-m length of core, complete the core module.

The boom/solar array drive, shown in Figure 3-23, contains two separate drive units in one package; a solar array drive and a drive unit to rotate the OCDA boom. Both drive mechanisms apply torques against the OCDA mast structure and both driving functions are completely independent of each other. In summary:

- Solar Array Drive - The solar array is supported from a flange at the upper end of the drive unit. The solar array drive contains a slip ring assembly capable of transferring 250 kw at 200 v. Rotation rates are orbital speed (approximately 1 revolution every 90 min) and a higher speed tracking mode

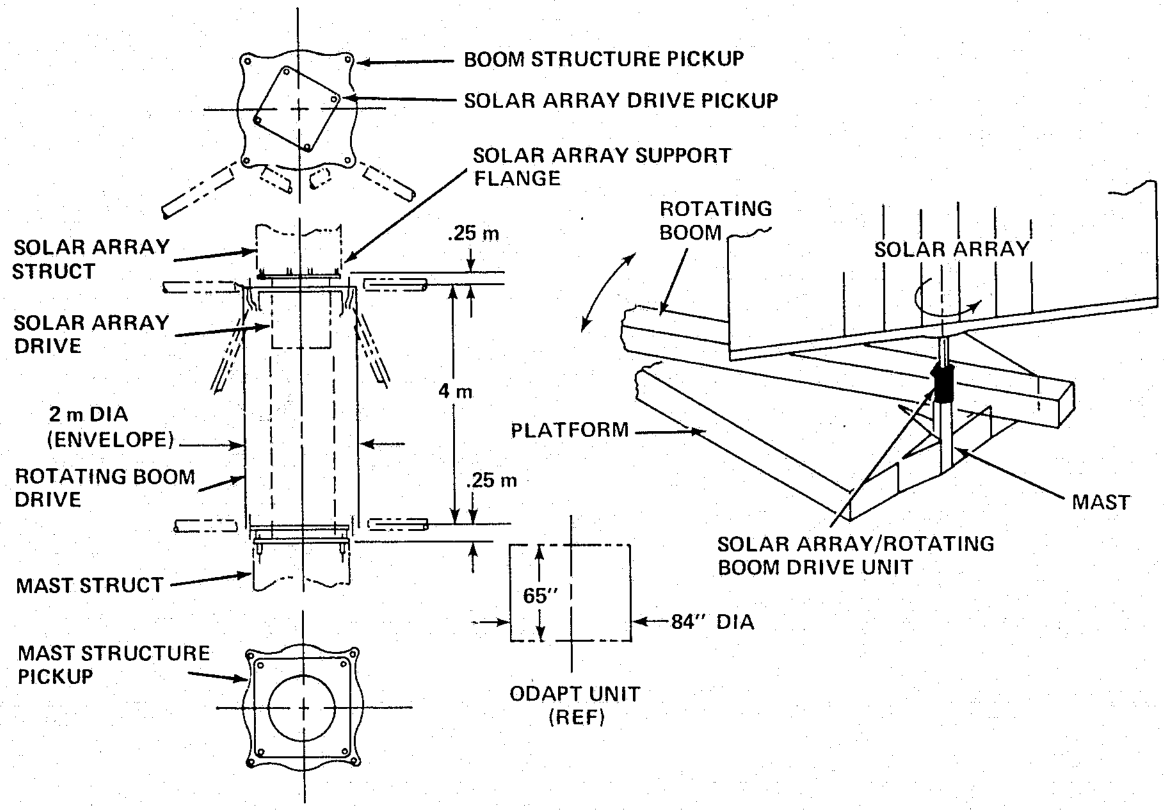


Figure 3-23 OCDA Solar Array/Rotating Boom Drive Unit

- Boom Drive - The rotating boom structure is mounted to the outer housing of the drive unit. This drive unit provides structural support as well as rotating torque for the boom. All rotating parts, motors, bearings, etc. are enclosed within this unit.

The design life of the solar array/boom drive Unit is 10 years.

3.4.1.3 Solar Array - The OCDA solar array shown in Figure 3-24 consists of a number of array modules mounted on the "upper" end of the rotating boom mast. The array is intended to serve in two configurations; a modest sized array (19.2 kw) to provide "housekeeping" power for the platform functions and moderate experiment load as well as a very large array (250 kw) for a specific experiment requiring high power. The array design is modularized to facilitate assembly and match the deployed array with the power requirements.

The basic component of the modules is an expanded capacity SEPS solar array. The capacity is increased by extending the deployed length by 50%. The array modules (which each contain their own extension mechanisms) are deployed side by side to achieve the required power level (250 kw maximum). The entire array consists of a central module and 12 add-on units. The overall size of the full array is 48 x 54 meters.

The central module structure is prepared by erecting and securing the folded structure. The Astromast, substrate and "STEM" devices are attached. The assembly is now installed on the solar array drive unit. The STEM guidance units and the Astromast propelled substrate are deployed. This initial array (and every additional module) will produce 19.2 kw of power. Subsequent modules are assembled and attached outboard of the preceeding module. As each new module is attached, electrical connections for

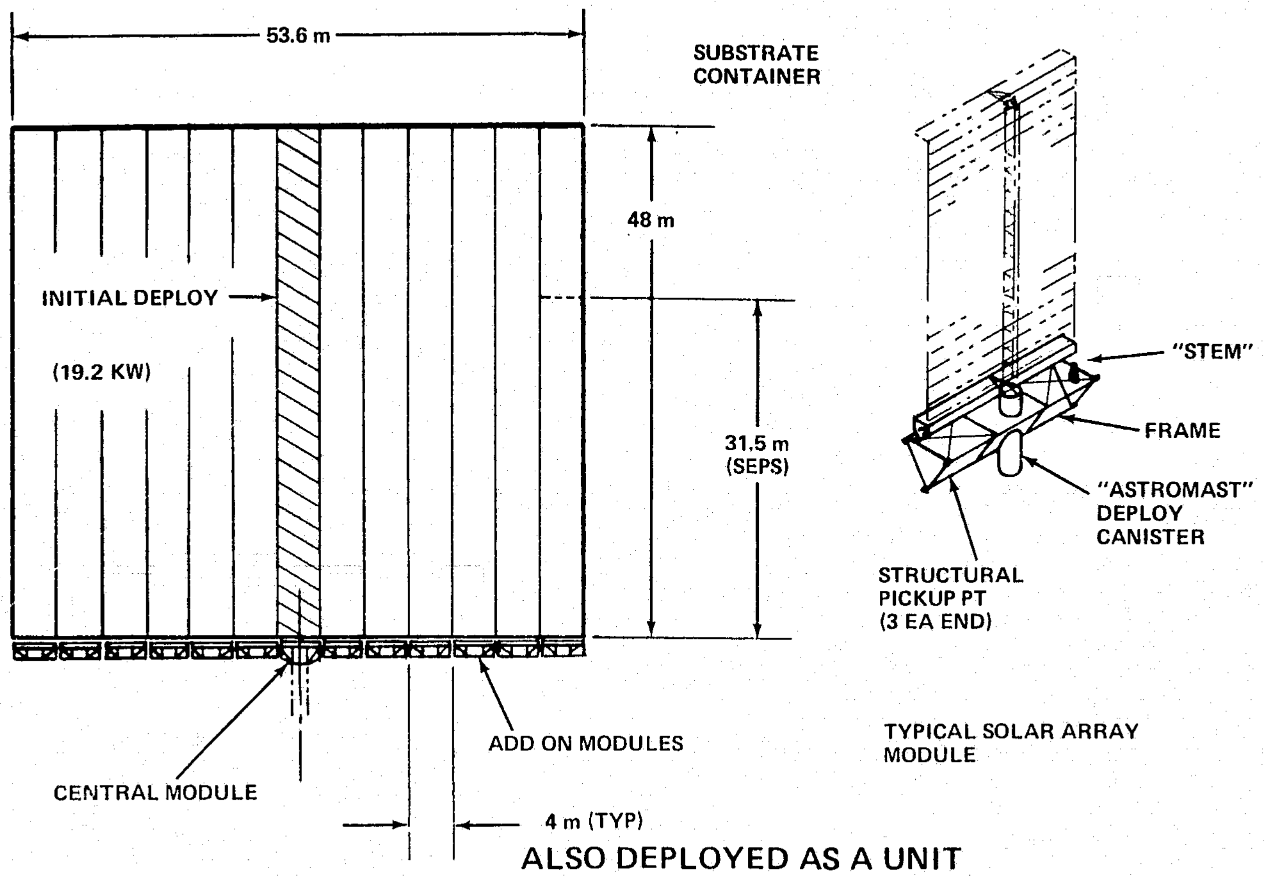


Figure 3-24 OCDA Solar Array (250 kw)

deployment power and solar power output are made. The close proximity of the solar array components to the boom allows all important assembly functions to be performed within easy reach of the boom mounted manipulator.

3.4.1.4 Rotating boom - The major elements of the rotating boom are the 110-m long x 4 m square structure that supports a manipulator carriage and materials traveller. These elements are conceptually shown in Figure 3-25.

The manipulator used on the OCDA is a standard Shuttle RMS. The manipulator is attached to a carriage mounted on the rails and can move along the boom. The maniuplator carriage is unpowered and is moved from one place to another by the traveler. When the manipulator carriage is at the desired location, it is locked to the rail and uncoupled from the traveler. An electrical umbilical runs from the umbilical reel down the boom to the docking port on the core module. Operation of the manipulator is accomplished from the RMS operator station in the shuttle, using lights and TV cameras on the manipulator to provide visibility. The umbilical is hard wired to the RMS, reeling in and out being accomplished by rotating the reel and manipulator together, each revolution of the reel providing a 4 m relocation of the carriage. Erectable fairleads support the umbilical along the boom.

The traveler is a powered cart that moves up and down the boom to relocate the manipulator carriage and bring men and materials to the work site. The traveler runs on the boom rails and is moved by an electric traction drive acting against the lower rail. Power to run the traveler is drawn from a power pickup rail mounted on the boom structure.

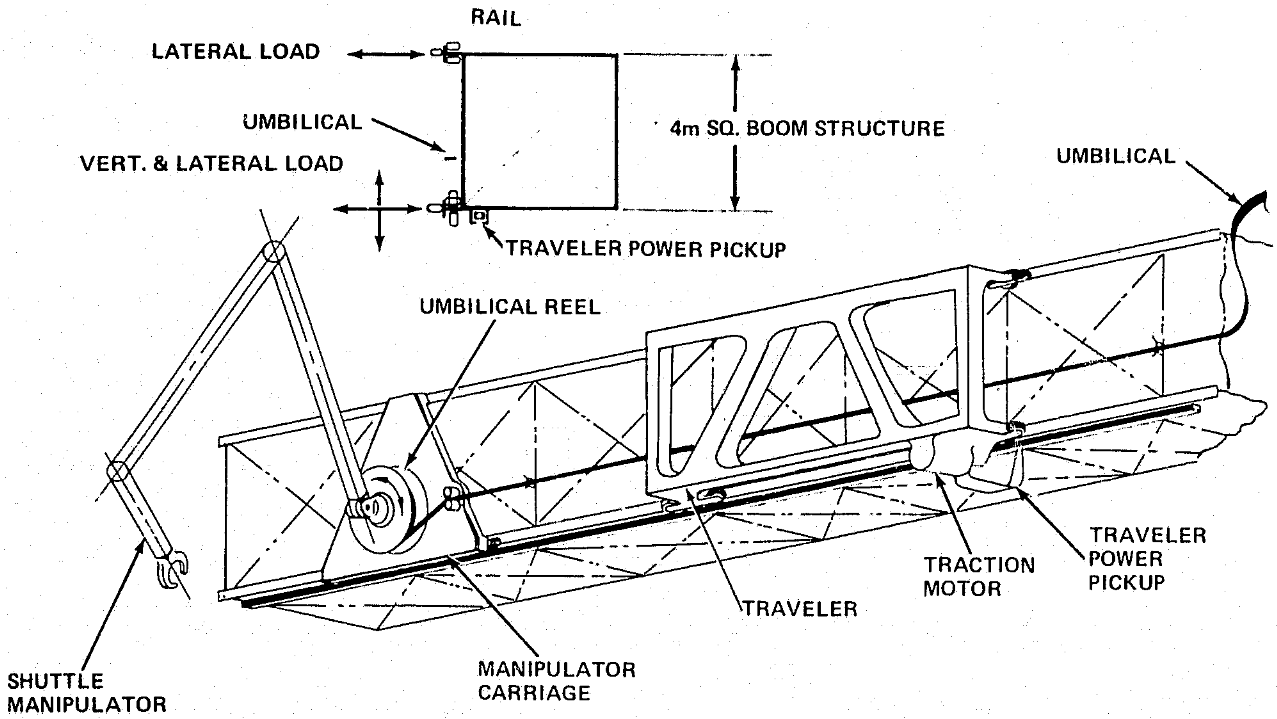


Figure 3-25 OCDA Rotating Boom Manipulator and Traveler

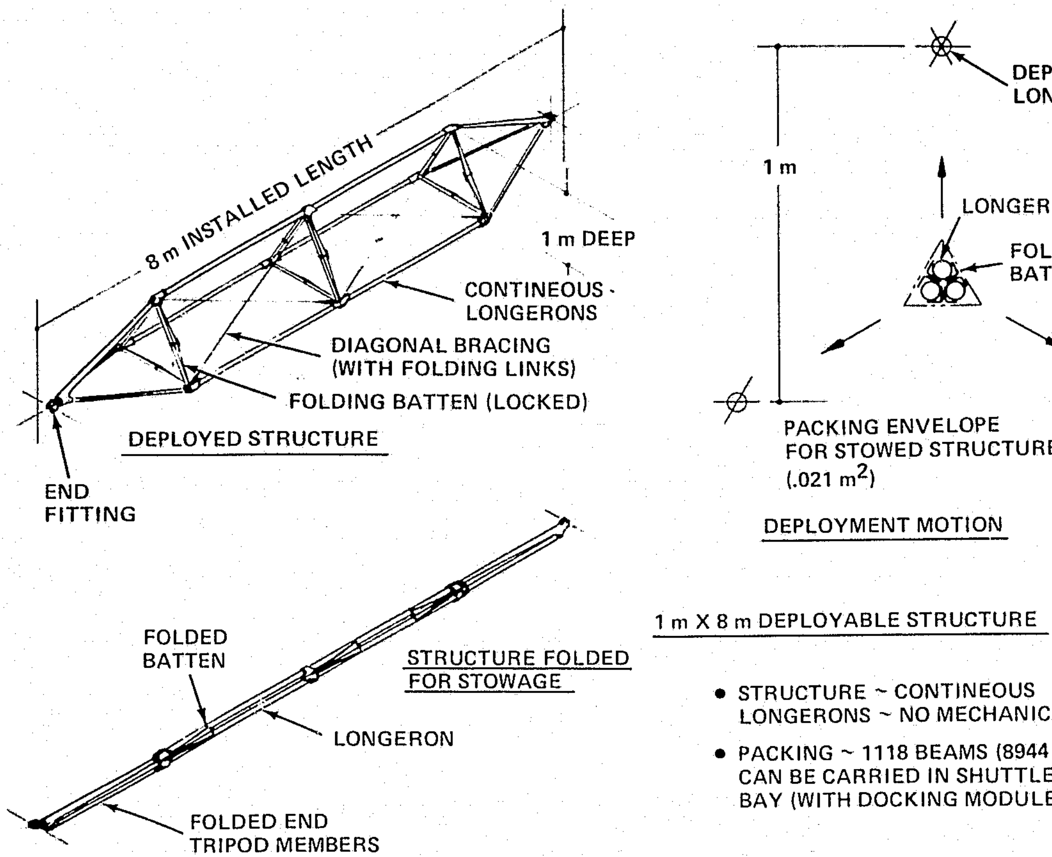
3.4.2 Building Block Structure

The structure shown in Figure 3-26 has a 1-m depth triangular section and is shown in both 8 and 16 m lengths. The 8-m length is compatible with the OCDA structural arrangement. Because structures this size fit easily within the shuttle cargo bay, continuous longerons are used to eliminate the structural deadband that results from joint clearances. The structure is compacted by folding the battens of each bay, shrinking the cross-section. The folded batten is entrapped between longerons, which provide support during liftoff. On deployment, the batten unfolds and is locked in the extended position by an overcenter lock. Cross bracing is used to stabilize each bay. A set of folding links takes up the cable slack when the structure is retracted. This deployment approach can be used for structures to be fastened end-to-end to make continuous members.

The retracted structure has a cross section area of 0.021 m^2 and a volume of 0.335 m^3. A dedicated shuttle flight could deliver 8944 m of structure (approximately 1000 m are required for the OCDA platform structure). The structure is held in the retracted position by pins that hold the longerons together. Deployment is initiated by pulling the lock pins with a lanyard or pyro actuator. The structure is deployed by the energy stored in the batten lock torsion springs.

3.4.3 Platform Assembly Fixture

To minimize installation time and insure dimensional repeatability, a subassembly fixture is utilized in the orbiter payload bay. The fixture, shown in Figure 3-27, uses adapters that pick up the orbiter payload bay longeron attach points. The fixture is constructed of composites to minimize dimensional changes and locates four nodal fittings for a 8 m x 8 m x 4 m platform element. Five of the six element faces are assembled using deployable 8-m beams, 4-m tubular posts, and tension rods. The aft face including two 4-m posts are assembled and locked in position. The side beams, side tension rods, and



- STRUCTURE ~ CONTINEOUS LONGERONS ~ NO MECHANICAL DEADBAND
- PACKING ~ 1118 BEAMS (8944 m) CAN BE CARRIED IN SHUTTLE CARGO BAY (WITH DOCKING MODULE & PALLETS)

Figure 3-26 OCDA Candidate Structural Building Block

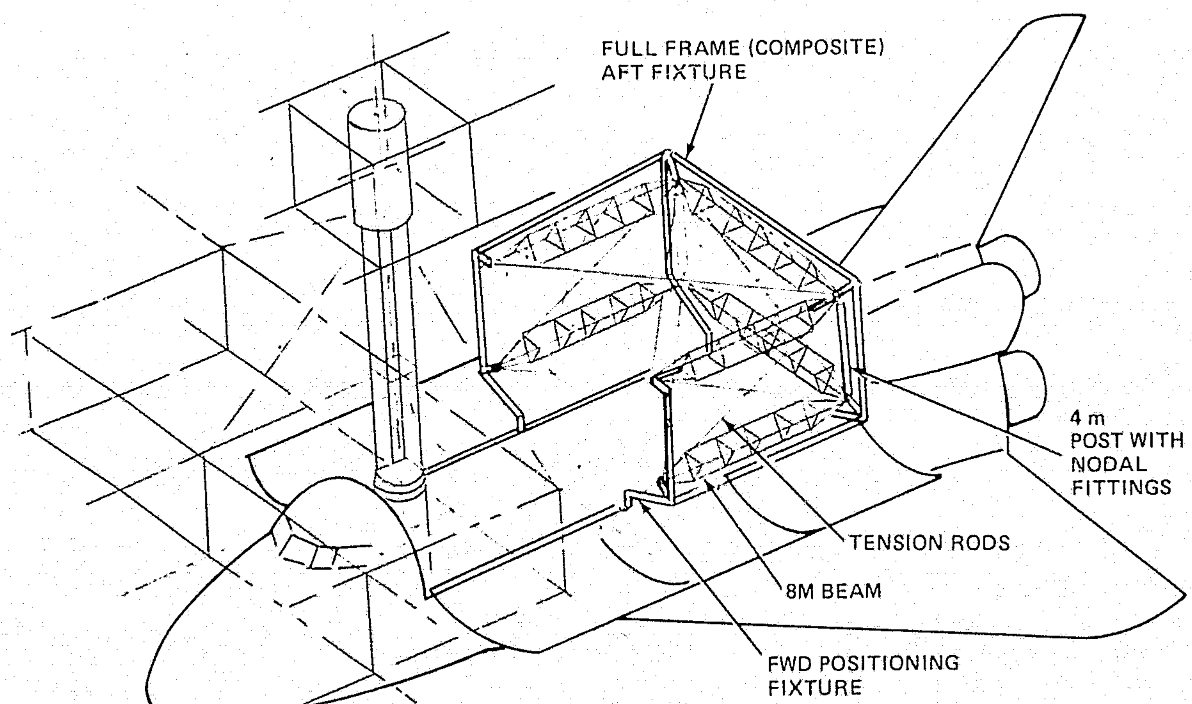


Figure 3-27 OCDA Platform Assembly Fixture (On Orbiter)

upper and lower tension rods are positioned and adjusted for length using the appropriate nodal clevis fitting. The element is removed from the fixture by the orbiter RMS and transported to the installation area.

3.4.4 Platform Assembly Method

Figure 3-28 illustrates the nodal joining of 8 m x 8 m x 4 m partial elements to form the full platform. A completed element corner tubular post, A , with crew toe holds or reaction hardpoints were assembled and adjusted in the aft face of the cargo bay assembly fixture. The forward ends, B and C , of two partially assembled cubes, with their appropriate probe fittings are positioned and soft mated to the nodal drogue fitting at point A . A final hard mate is made by turning a manipulator compatible device that is an integral part of the probe end fitting. The tension rods, as in D , have a similar probe fitting that is soft mated and hard mated by a manipulator.

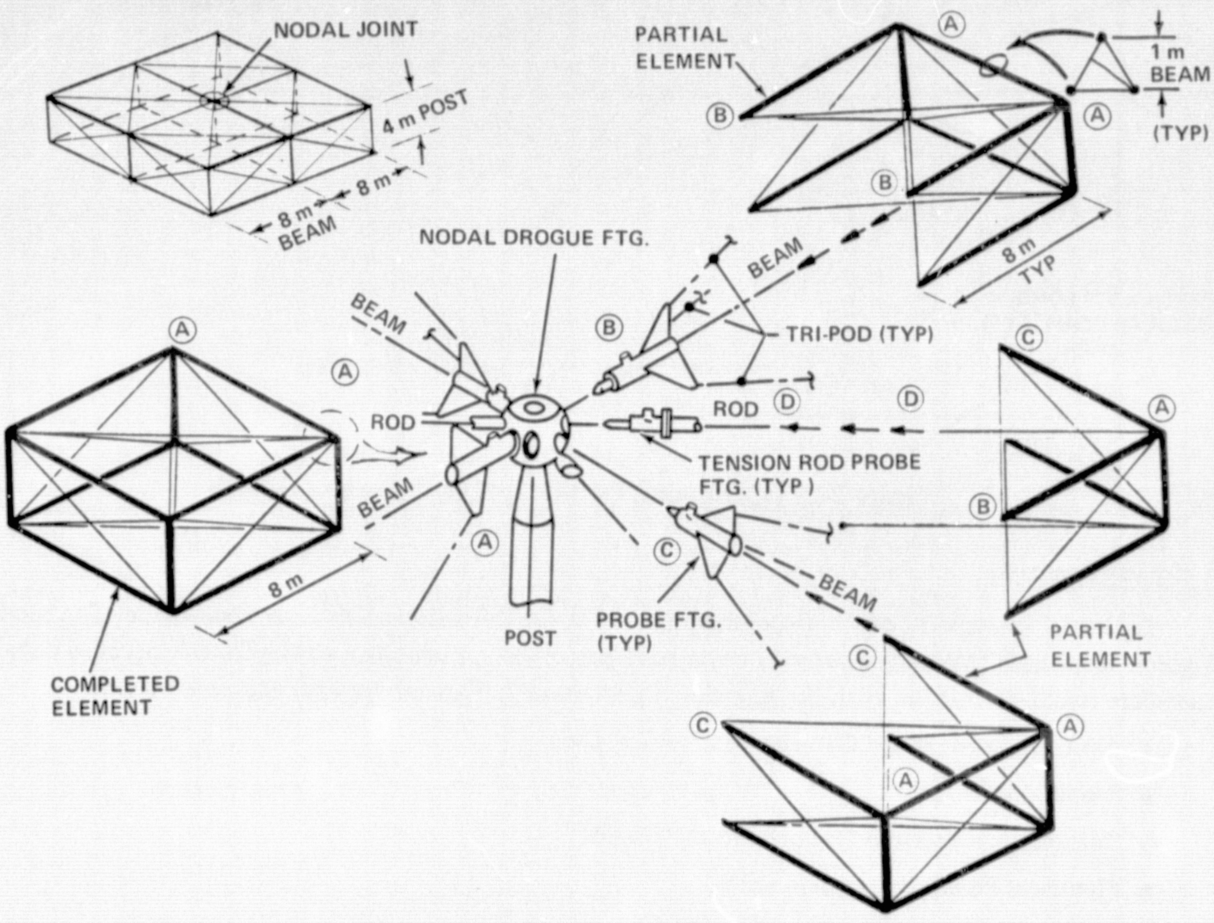


Figure 3-28 OCDA Platform Assembly Method

Figure 3-29 is a more detailed layout of the joint. The nodal drogue fitting, with 12 parts, is an integral part of the tubular vertical post. The probe is integral to the triangular beams and tension rods. These probes utilize spring-loaded pawls for capture and soft mate and a drive mechanism that retracts the probe shaft until the pawls and probe anvil are seated in the drogue effecting the hard mate.

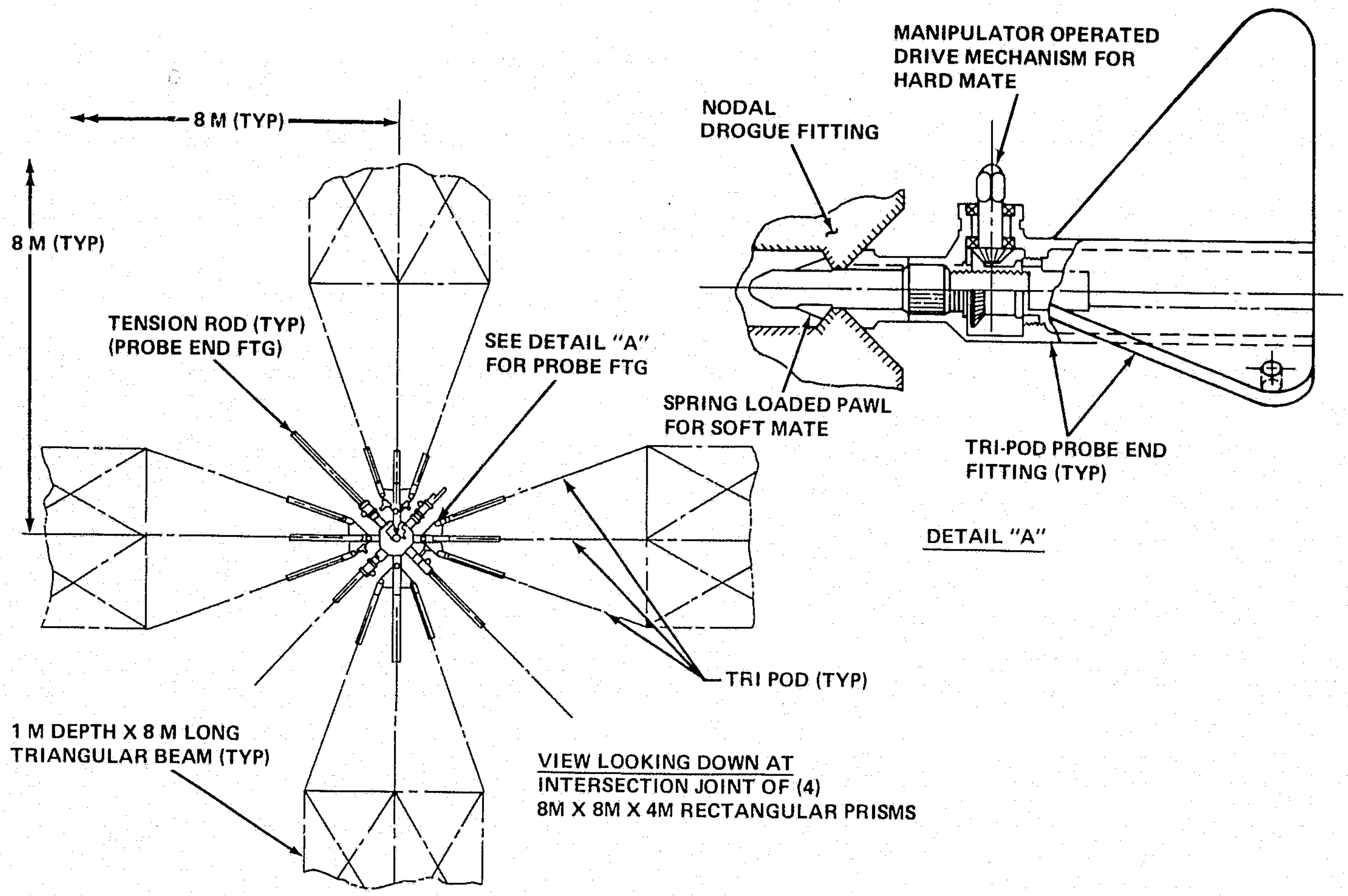


Figure 3-29 OCDA Joint Design Option, Probe and Drogue

3.5 SUBSYSTEMS

An initial assessment of the requirements for the OCDA subsystems have been made. The modular mission spacecraft (MMS) requirements were evaluated for applicability to the OCDA because developed hardware could be utilized with the associated cost savings. The subsystems addressed were:

- Attitude Control and Orbitkeeping (AC & OK)
- Propulsion
- Communications and Data Handling (C&DH)
- Electrical Power Subsystem (EPS)
- Platform Logistics and Assembly (PL&A).

The MMS attitude control sensors and control electronics plus the MMS C&DH computer meet the OCDA attitude control and orbitkeeping requirements. Propulsion requirements for attitude control and orbitkeeping are specific to the OCDA, therefore different approaches were evaluated and recommendations made. OCDA Communication and data handling requirements are similar to MMS requirements so the MMS module could be used. The MMS EPS module meets the basic OCDA housekeeping power requirements, therefore it could be utilized. Additional EPS equipment is required to

meet much higher power needs for construction, orbitkeeping and experiments. The PL&AS comprises that equipment needed to construct the OCDA and support experiments, including transportation of men and material to work sites.

3.5.1 Attitude Control & Orbitkeeping Subsystem

The basic attitude control requirements is to maintain the long-axis of the platform earth-oriented, with the platform maintained in the orbital plane. The boom is then nominally earth-oriented and the rotation axis of the solar array is 26° off perpendicular to the orbital plane. This orientation approach minimizes the gravity gradient effect with and without the orbiter although system sizing is without the orbiter. It is assumed that the orbiter augments the attitude control as required. The orientation also permits gravity gradient unloading maneuvers to be considered in future studies.

The large array area results in a relatively low value (1.5) for the ballistic coefficient for the overall OCDA in the nominal orientation. Orbit decay of 10 n mi (18.5 km) from the 190 n mi (352 km) altitude in six months is unacceptable and orbitkeeping is required. The drag force causing this effect is equivalent to a 0.18 lbf (.8 N) thrust acting continuously.

The attitude control concept selected uses the NASA proposed Multi-Mission Spacecraft ACS module for the sensing function and the Communications and Data Handling module for signal processing and control law computations. The system consists of an inertial reference assembly updated by sun sensors and star trackers. The earth-oriented reference is obtained from attitude and ephemeris information which is used to generate inertial reference assembly commands via on-board software. The specific actuators (e.g. wheels, and thrusters), which are tailored to the spacecraft requirements, are made compatible with the NASA standard module by drive electronics. The candidate equipment listed in Figure 3-30 reflects NASA standard subsystem components weights for the sensors and electronics.

Equipment	Qty	Mass	
		lb	Kg
MULTI-MISSION SPACECRAFT MODULE			
STRUCTURE	1	45	100
INERTIAL UNIT	1	12	26
MAGNETOMETER	3	2	5
STAR TRACKER	2	10	22
INTERFACE ASSY. & DRIVE ELECTRONICS	1	23	50
SUN SENSORS	9	13	28
REACTION WHEELS	3	427	941
		532	

Figure 3-30 Attitude Control & Orbitkeeping Subsystem Weights (Non-Redundant)

A more detailed analysis should be made to determine the performance impact of moving the boom relative to the platform. In particular, the momentum exchange during a repositioning maneuver and the effect of the changed configuration on the disturbance torques must be considered. Boom reposition rate constraints should be developed. Similar analyses should be conducted for conditions during the construction scenario. Platform maneuver requirements based on experiment missions, momentum unloading or boom offset inertia balancing should be developed. The ability of the orbiter to augment control of the OCDA when docked must be evaluated.

3.5.2 Propulsion Subsystem

3.5.2.1 Attitude Control - Actuator options have a major impact on system weight. Mass expulsion using various propellants were compared with momentum storage using different unloading techniques. The momentum storage devices consist of Control Moment Gyros (CMG) and reaction wheels. The high momentum-storage-to-torque ratio favors reaction wheels as reflected in lower weights for the wheel systems. Gravity gradient unloading was ruled out at this time in favor of jets and wheels to avoid operational attitude constraints.

The lowest weight of 3350 lb (1521 kg) was calculated for wheels with electric propulsion unloading but must also include 1640 lb (744 kg) of propellant which is resupplied at 6-month intervals. The next to lowest weight is for the wheels with superconducting magnets for unloading, requiring only 450 lb (204 kg) of helium at 6-month intervals. This system also has a distinct power advantage over the ion thrusters, especially when the long eclipse periods are considered. However, these systems are not state-of-the-art, therefore a more conventional system of hydrazine thrusters and wheels were selected for attitude control. Future studies should include a more thorough evaluation of actuator technology requirements.

3.5.2.2 Orbitkeeping - The orbitkeeping approach selected consists of an ion thruster module which fires continuously to oppose the nominal drage force. The system has been sized including batteries for power during the occultation period. Two modules are oriented in the plus and minus velocity vector directions. This provides the more flexible ability to perform intermittant attitude corrections and allows operation with the +X axis oriented along the plus or minus velocity direction. Propulsion subsystem mass is shown in Fiqure 3-31.

Equipment	Qty	Mass	
		lb	Kg
HYDRAZINE THRUSTERS (4-.025 lfb, 2-0.1 lbf, 4-0.5 lbf)	10	32	70
HYDRAZINE AND HELIUM TANKAGE	4	777	1,712
HYDRAZINE	-	7575	16,700
THRUSTER MODULE STRUCTURE	2	85	188
ORBIT KEEPING MODULE	2	45	100
ION THRUSTERS (.05 lbf)	8	100	220
ARGON TANKAGE	2	53	116
		8674	

Figure 3-31 Propulsion Subsystem Weights

3.5.3 Communication & Data Handling (C&DH) Subsystem

The OCDA must be capable of being tracked between Orbiter visits and respond to ground commands. Data transmission provides assurance that subsystems are operating satisfactorily and that experiments are performing as planned. During docking operations, the Orbiter must have the capability of controlling the OCDA for safe operations. Certain OCDA and experiment operations will be programmed to occur automatically without ground control intervention. The C&DH will provide the capability for remote manipulator control experiments from the ground.

The MMS C&DH is used, because the OCDA C&DH requirements are similar to those provided by the MMS C&DH. This module includes provisions for certain mission peculiar equipment such as a tpae recorder if required. Additional equipment needed for TV transmission and TDRS interface includes such equipments as a high gain antenna, tracking and drive electronics, and a wide band transmitter.

C&DH weights for the MMS module have been extracted from the NASA specification S-700-15, as shown in the weight statement of Figure 3-32. A weight allowance for the S-band omni antenna coaxial cable is provided since they will be mounted some distance away from the MMS module.

Equipment	Qty	Mass	
		lb	Kg
MULTI-MISSION SPACECRAFT MODULE	1	123	270
COAXIAL CABLES	2	14	30
WIDE BAND COMMUNICATIONS			
HIGH GAIN ANTENNA SYSTEM	1	36	80
TRANSMITTER	1	5	10
CONVERTERS, ETC.	1	2	3
		180	

Figure 3-32 Communication & Data Handling Subsystem Weights

Studies and simulations are needed to define the procedures & necessary bits of information needed for maniuplators remote operations. Multiplexed operator signals require processing to control the manipulator. A number of video displays are needed by the operator(s) for feedback to successfully control one or more manipulators. These requirements could have a large impact on the C&DH design.

It has been assumed that a single high-gain antenna is mounted on the core end of the platform and that omni antennas are also mounted on the same end at the platform corners. Platform structure, boom, and solar array interfere with the antenna operation; therefore, the question of location needs further analysis.

3.5.4 Electrical Power Subsystem

Experiment power requirements drive the size of the OCDA solar array. Some experiments require continuous power, therefore batteries have been sized to meet power demands during earth eclipse. In addition to the subsystems requiring power, other equipments have been considered, such as illumination, boom drive and traveller, and the solar array drive. A large solar output is required compared to experiments (etc.) needs due to system inefficiencies.

A 200-volt distribution system was selected to reduce the weight penalty associated with a 28-volt system. The total system weight can be reduced if the distribution conductors are designed to be functional elements in the structure. A substantial efficiency and weight penalty is paid by using readily available 28-volt batteries. The penalties can be reduced if batteries can be built and operated in high-voltage configurations, eliminating large step-down and step-up conversions in chargeing and discharging. Microwave experiments require 20-40 kvdc, and the weight of conversion equipment should be included in an eventual study to optimize distribution voltage.

The OCDA power requirements vary considerably, from approximately 7 kw needed during construction and 10 kw between Shuttle revisits to higher values up to 210 kw required by experiments (see Figure 3-33). This indicates that all array elements need not be deployed during construction but could be deployed subsequently, when power is required by experiments.

SUBSYSTEM	POWER AT BUS, W			POWER FROM ARRAY W
	HOUSEKEEPING	CONSTRUCTION*	EXPERIMENTS	
C & DH	250	250	250	830
ACS	315	315	315	1050
ORBIT KEEPING	8700	*	8,700	29000
SOLAR ARRAY DRIVE	90	90	90	300
LIGHTS	150 – 350	4,000	150 – 350	500 - 1170
BOOM DRIVE		600	600	2000
TRAVELLER		60 – 110	60 - 110	200 - 370
BOOM RMS		900 – 1400	900 - 1400	3000 - 4700
EXPERIMENTS			64,000	210,000
TOTALS	9505 - 9705	6,215 – 6,765	11,065 - 75,815	246,880 - 249,420

*ORBIT KEEPING SYSTEM ADDED ON LAST FLIGHT

Figure 3-33 Electrical Power Subsystem Requirements

The multi-mission spacecraft standard module is again selected, specifically for housekeeping power. Orbitkeeping ion engine power, construction needs, and experiment power will be controlled by additional equipment. Figure 3-34 contains a list of EPS weight contribution to the OCDA.

3.5.5 Platform Logistics & Assembly Subsystem (PL&AS)

Materials must be unloaded from the Orbiter payload bay and transported to the subassembly or assembly site as needed. Subassemblies and assemblies require structural positioning aides. Also this subsystem should support the subsequent installation of experiments.

The implementation of the PL&AS requirements are dependent on the assembly approach. The method selected to transfer men and materials relies on the Boom. The Boom is positioned over the Orbiter payload bay enabling the Orbiter manipulator to transfer equipment from the Payload bay to the boom traveller. The boom is rotated to the assembly site while the traveller carries men and material. At the assembly site, the boom manipulator removes the traveller equipment and positions the equipment for assembly. When the boom manipulator requires relocation, the traveller is coupled to it and moves the manipulator to the new work area. Equipment is listed in Figure 3-35.

Equipment	Qty	Mass	
		lb	Kg
MULTI-MISSION SPACECRAFT MODULE	1	265	583
CORE WIRING	-	1332	2936
PLATFORM			
POWER REGULATION	1	205	452
WIRING	-	2235	4924
ORBIT KEEPING BATTERIES	18	825	1818
BOOM WIRING	-	4394	9688
SOLAR POWER DISTRIBUTION	-	794	1746
SOLAR BLANKET & DEPLOYMENT MECH.	13	4369	9634
		14,418	

Figure 3-34 Electrical Power Subsystem Weights

Equipment	Qty	Mass	
		lb	Kg
BOOM DRIVE	1	952	2100
BOOM MANIPULATORS	2	786	1734
TRAVELLER	1	65	143
PAYLOAD BAY ASSEMBLY FIXTURE	1	98	216
FIXTURE MANIPULATOR	1	393	867

Figure 3-35 Platform Logistics & Assembly Subsystem Weights

Future analysis should investigate the best method for controlling translation of the traveller and boom manipulator. The approach to transferring control signals to the boom manipulator requires analysis. The baseline vehicle for study shows a hard wire connection to the manipulator that is rolled out or in when the manipulator is translated. The design of the traveller power pick-up from boom mounted rails presents a challenge, as is the method of joining boom rails during assembly. The Orbiter and boom manipulator control fidelity should be examined and compared with the specific tasks required of the manipulators. Manipulator controls and displays in the Orbiter will have to be evaluated considering task requirements. Also, manipulator camera locations and illumination at the work site must be evaluated. The location and method of controlling the boom slewing required investigation as well as Orbiter payload bay equipment needs. This equipment must provide support for OCDA beams etc. during launch and also provide ease of retrieval during construction.

Section 4

ASSEMBLY OPERATIONS

Different approaches to assembling the OCDA were studied that embodied assembly scenarios for future large structure missions. One assembly approach given emphasis relied on existing STS equipment and is mainly dependent of EVA construction techniques. An alternate, and recommended approach, studied assembly of the OCDA using higher technology maniuplators. Both approaches were found to need three Shuttle flights to construct the OCDA. However, the manipulator assembly approach can be completed in less construction time than the EVA approach.

4.1 ASSEMBLY APPROACHES

The five representative future missions (reference Figure 2-2) were studied for construction functionial requirements. This data was utilized to develop approaches to constructing the OCDA. Four approaches were assessed:

- Manned assembly
- Man assisted by machine
- Machine assisted by man
- Major assembly by machine.

4.1.1 Manned Assembly

The crew removes collapsed beams from the Orbiter bay, deploys them and verifies that all links are locked. Beams are transported by the crew either using MMU's to fly the beams to the assembly location or transfering them hand-to-hand over existing structure. At the assembly site, the crew maneuvers the beams into position, fastens them to existing attachment fittings, and attaches stays for positioning. As each "cube" is completed, alignment is checked optically and adjustments made where necessary.

This approach appears viable for constructing the OCDA; however, it was not chosen as the approach for study emphasis. The construction of future large structures must rely on machines to meet productivity goals, and therefore more mechanized construction should be an integral part of the OCDA assembly.

4.1.2 Man Assisted by Machine

Beams are deployed by the crew and installed in a subassembly fixture. A manipulator is used to remove the subassembly from the fixture and position it on a traveller for transportation to the assembly site. Here another manipulator removes the subassembly from the traveller and positions the subassembly for attachment to the existing structure by a crewman.

4.1.3 Machine With Manned Assistance

Beams are space fabricated and installed in a subassembly fixture by manipulators. After the subassembly is complete, it is transported to the assembly site where remote manipulators position the subassemblies and completes beam attachment. EVA construction personnel check the assembly alignment.

This method of constructing the OCDA could be implemented if an automatic beam fabrication plant is available and if a second orbiter RMS operators console is provided. A further need is that higher fidelity manipulators be developed to enable beam attachment tasks to be done effectively.

4.1.4 Major Assembly by Machine

The key to high assembly rates is the automatic, continuous, flow of assembled structure from an orbital factory. This concept relies on a number of fabrication plants producing structure in parallel. First, the factory is assembled in orbit including its support systems such a s electrical power and control. Raw material supplies are maintained on hand for the fabrication plants.

A one-of-a-kind orbital structure, such as OCDA, does not appear to warrant high investiment in capital equipment associated with high production, multiple fabrication and assembly. The functions of control, power, etc, for highly automated assembly can be handled by a completed OCDA as part of a continued utility program.

4.2 ORBITER SUPPORT

Data was extracted from the Shuttle Orbiter Payload Accommodations Document that related to construction and crew activities. This data was used as the basis for planning OCDA flights and determining the impact of crew activities on the Orbiter. Baseline Orbiter support provides consumables and accommodations for a crew of four during a seven-day flight. Support is also provided for two men to conduct two EVA's of six hours. The necessary equipment for three additional crew men, manned maneuvering units and a second remote manipulator system are payload chargeable. Any provisions required to support the OCDA, such as a docking module are also chargeable to the payload.

4.3 CREW OPERATION ASSUMPTIONS

The OCDA design is presently conceptual. Definition of crew operations requires a lower level of detail than is at hand, therefore the following assumptions have been made to establish these operations:

- Boom remote manipulator operated from Orbiter
- Illumination adequate for tasks
- Construction team consists of two EVA crew and a manipulator operator.

4.4 ASSEMBLY OPERATIONS

The four approaches discussed in Subsection 4.1 were evaluated for OCDA construction. One of the study objectives "The OCDA must utilize STS elements" was dominent in early thinking and led to study of the "Man Assisted by Machine" approach. This approach relies on EVA construction supported by the Orbiter manipulator and a second identical manipulator mounted on the boom. Later, the "Machine Assisted by Man" approach was studied. This approach utilizes manipulators as the principle assembly mechanism. The assumption here is that high fidelity manipulators are available and a second manipulator control station is provided in the Orbiter.

4.4.1 Man Assisted by Machine Operations

A method for constructing the relatively large structure of the OCDA while operating from the Orbiter was formulated (see Figures 4-1 through 4-4). The grid structure of the OCDA led to the breakdown of the structure into the subassembly of open cubes. A fixture is assembled on the open payload bay which positions posts and beams for assembly into open cubes. Open cubes are then transported to the assembly site for attachment to the existing structure. The open cubes are moved from the subassembly fixture by the orbiter manipulator, attached to a traveller on the rotating boom for transportation to the assemble site, removed from the traveller by a boom manipulator which also positions the open cube for assembly. The open cube is attached to existing structure and later alignment is done by EVA.

- Open Cube Assembly - A subassembly fixture shown in Figure 4-1 is assembled in the Orbiter payload bay. One end of a beam is attached to the fixture, deployed, and then the other beam end is fastended in position. This fixture is used to assemble ¾ cube platform sections or ½ cube sections as required.
- Cube Transportation - The subassembly, consisting of a partially built platform cube (Figure 4-2), is released from the assembly fixture and moved to the boom traveller by the Orbiter RMS. Support arms on the boom traveller grasp the open platform cube at the posts. This subassembly is then transported to the assembly site by the boom traveller where it is removed and positioned for assembly by the boom RMS.
- Cube Attachment - The open cube subassembly is positioned for beam attachment by the boom RMS. The RMS operator is located in the Orbiter using two split TV displays for position feedback information. Beams are connected to the existing structure and locked secure as shown in Figure 4-3.
- Alignment - One side of the open cube subassembly is structurally complete when it is removed from the assembly fixture (i.e., diagonal stiffening stays are tensioned to specification) and the beam lingths were "set" in the subassembly fixture. However the horizontal and vertical position of the cube is dependent on tensioning of the stays; after each cube is assembled to the platform, alignment is required. A prism is temporarily attached to the assembly fittings and an optical beam is reflected from the prism to a Theodolite reference providing cube alignment information as illustrated in Figure 4-4. Tension stays can now be adjusted as required.

The Man Assisted by Machine construction approach was developed in three Shuttle flights. Figure 4-5 illustrates the sections of the OCDA to be constructed on each flight.

The object of the first flight is to establish a satellite that can operate autonomously and is stable for Orbiter docking. Also, it is desireable to assess the capability of performing operations required on subsequent flights. On the first flight, the core is deployed and docked to the Orbiter docking module, a single solar array element is deployed, the boom stub assembled, and core platform cubes constructed.

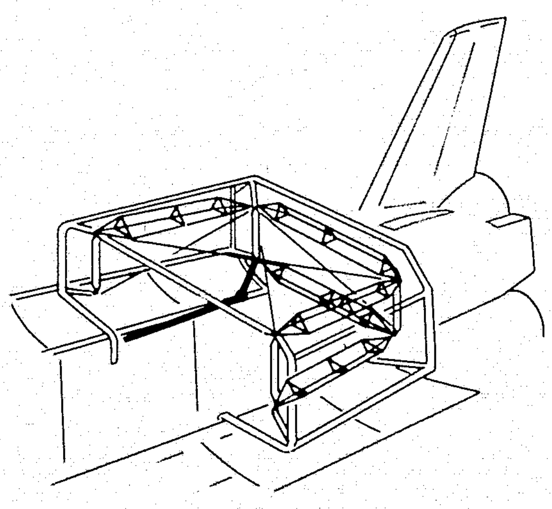


Figure 4-1 Open Cube Assembly

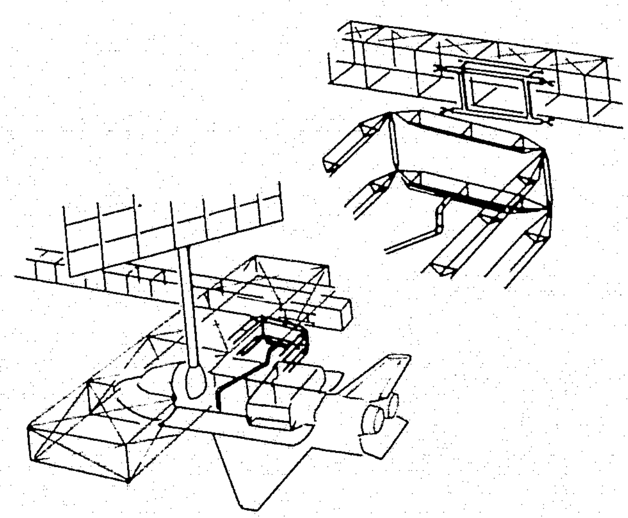


Figure 4-2 Open Cube Transportation

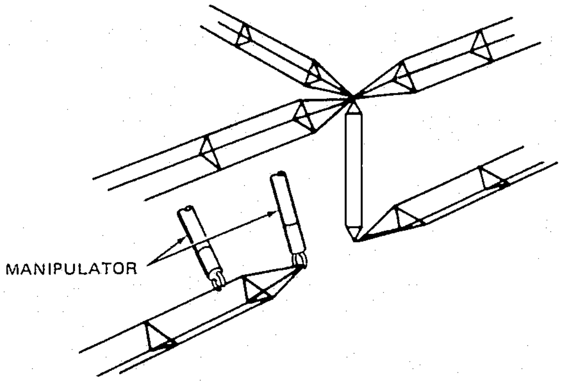


Figure 4-3 Cube Attachment

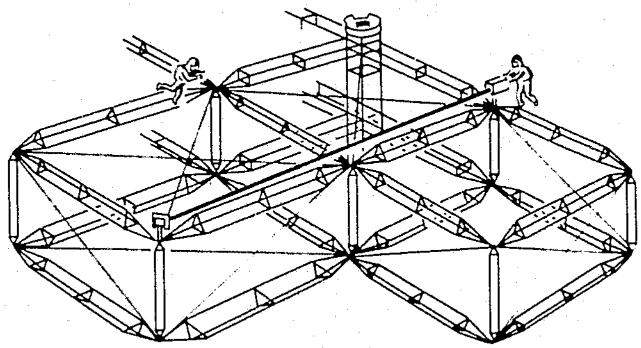


Figure 4-4 Optical Alignment

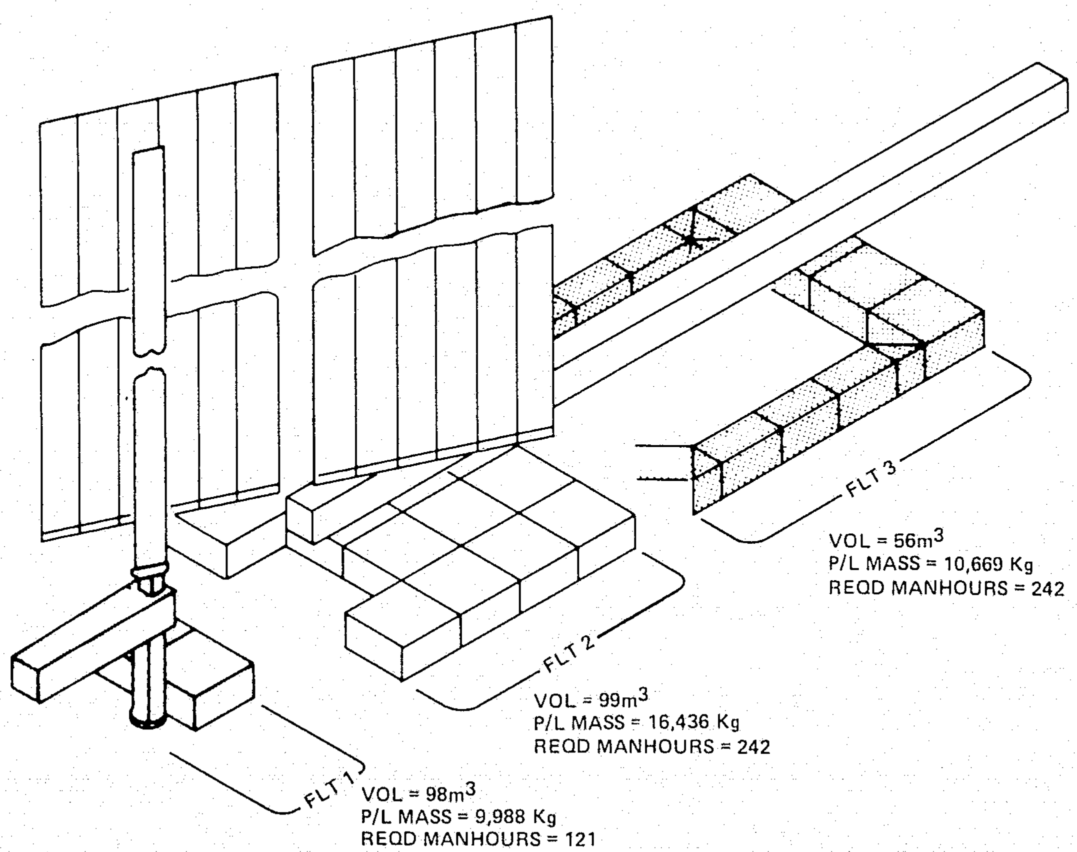


Figure 4-5 OCDA Assembly (Man Assisted by Machine)

The second flight domonstrates structure assembly techniques. The boom is constructed, solar array completed and a major portion of the platform is built.

The third flight provides experiment support requirements. The platform construction is completed, electrical power and mounting structure is installed for subsequent experiments.

Figure 4-6 illustrates the components required for the first construction flight of the OCDA and also indicated the volume available in the payload bay and the cg limit curve. The weight and cg location include the Orbiter docking module.

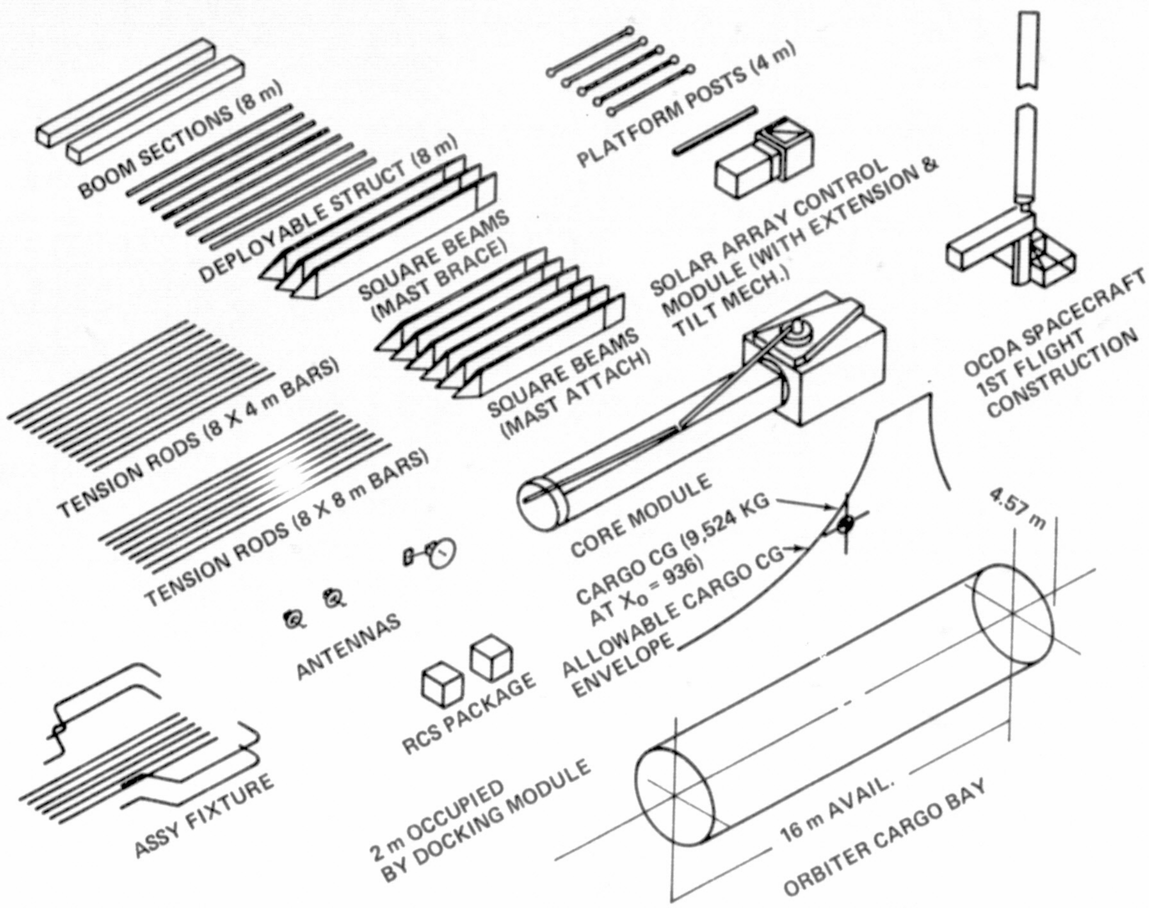


Figure 4-6 First Flight Payload

The 15-m length of core/mast consist of docking ring (passive) module, MMS modules, reaction wheels, boom/solar array drive unit and manipulator. This section is preassembled on earth and removed from the payload bay as one unit. The addition of the solar array module, RCS modules, and antennas, completes the requirements for an operational satellite.

Two 8-m lengths of deployable boom section and the deployable square beams, posts, diagonal rods and hardware required to construct the two mast support cubes of platform are also included.

The crew activity time to construct the OCDA is based on the Orbiter support capability. A single EVA construction period of 5¾ hours is available per day for each crew member. The time for the crew to complete construction tasks was estimated based on Skylab and simulation data. These times were used to plan flight activities. One construction crew is adequate for the first flight tasks and two crews are required for the second and third flights. Daily activities are shown in Figure 4-7.

4.4.2 Machine Assisted by Man

An alternate construction approach (Machine Assisted by Man) was also formulated. The concept was to mechanize the Man Assisted by Machine approach as much as possible using manipulators. Deployed beams were utilized similar to the previously discussed approach. Tasks were developed in somewhat greater detail because manipulators do not have the operational flexibility of the crew. Operational

FLIGHT 1 4 MEN – ONE SHIFT (3-MAN CONSTRUCTION CREW) (121M-HRS)

DAY 1	2	3	4	5	6	7
• ASCENT • DEPLOY CORE	• DEPLOY ONE S.A. ELEMENT • ASSEMBLE FIXTURE	• ASSEMBLE BOOM STUB • CORE BEAM CONST.	• CORE BEAM CONST.	• CORE BEAM CONST. • CORE CUBE ASSY.	• CORE CUBE ASSY. • INSTALL RCS	• INSTALL ANTENNAS • STOW FIXTURE • DESCENT

FLIGHT 2 7 MEN – TWO SHIFTS (6-MAN CONSTRUCTION CREW) (241.5M-HRS)

1	2	3	4	5	6	7
• RENDEZVOUS • ASSEMBLE FIXTURE • CONSTRUCT BOOM	• CONSTRUCT BOOM • CONSTRUCT PLATFORM	• CONSTRUCT PLATFORM	• CONSTRUCT PLATFORM	• CONSTRUCT PLATFORM	• ASSEMBLE SOLAR ARRAY	• STOW FIXTURE • RELOCATE RCS • RELOCATE OMNI ANTENNAS • DESCENT

FLIGHT 3 7 MEN – TWO SHIFTS (6-MAN CONSTRUCTION CREW) (241.5M-HRS)

1	2	3	4	5	6	7
• RENDEZVOUS • ASSEMBLE FIXTURE	• CONSTRUCT PLATFORM	• CONSTRUCT PLATFORM	• CONSTRUCT PLATFORM • INSTALL ION ENGINES	• INSTALL POWER CABLES	• INSTALL EXPERIMENT STRUCTURE • INSTALL LOGISTIC DOCKING PORTS	• STOW FIXTURE • RELOCATE RCS • DESCENT

TOTAL (604M-HRS)

Figure 4-7 Construction Operations Summary

times were established based on previously conducted studies and simulations (see NAS9-14319 "Orbital Assembly and Maintenance Study" performed by Martin.) Figure 4-8 shows a new smaller manipulator that is used to construct the open cubes in the assembly fixture. Typical operations and associated times for cube assembly are listed.

Three flights were again shown to be required to construct the OCDA with this assembly approach. A larger amount of structure could be assembled each day than is possible with the Man Assisted by Machine approach because operational time is not limited by 6-hours EVA and the associated preparations and post EVA tasks. However, Orbiter payload bay volume limitations constrain the first flight. The second flight constructs most of the platform, and the third flight completes the OCDA, including installation of platform wiring for subsequent experiment use.

EMPHASIZES:

- PARALLEL ASSEMBLY OPERATIONS
- CENTRALIZED STRUCTURAL FABRICATION

TYPICAL STUDY TREATMENT OF CONSTRUCTION OPERATION

ASSEMBLE 3/4 CUBE (13 TIMES)

TASKS	TIME, MIN
EXTRACT POST (ORB MANIP)	2
INSTALL IN FIXTURE (ORB MANIP.)	4
REPEAT ABOVE	6
EXTRACT FOLDED BEAM (ORB MANIP.)	3
PLUG INTO DEPLOYMENT STATION & DEPLOY	4
TRANSPORT BEAM TO FIXTURE (ORB MANIP.)	3
ATTACH BEAM (FIX MANIP.)	6
REPEAT ABOVE 5 TIMES	80
INSTALL HANDLING BEAM	6
ATTACH STAYS (10)	60
TENSION STAYS (2)	5
TOTAL	3 HR

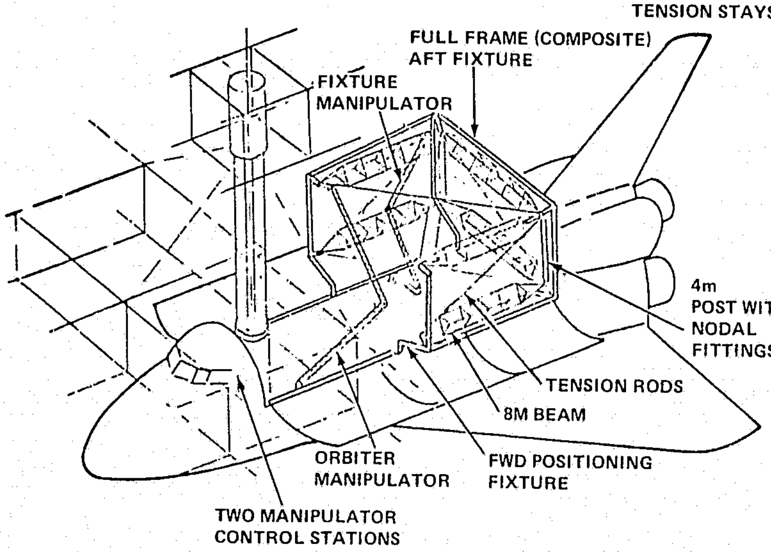


Figure 4-8 Platform Construction Approach

Section 5

OCDA DEMONSTRATION VALUE & CONTINUED UTILITY POTENTIAL

The areas of orbit construction technology requiring some level of orbit demonstration and test were identified during Task 1 and summarized in Figure 2-3. An important factor, which will be addressed during the add-on study phase, is to differentiate if a demonstration objective can be met using:

- A Shuttle sortie flight
- Shuttle supported by OCDA
- A permanent facility.

This section discusses the demonstration objectives met during the initial deployment of the OCDA and presents concepts for continued utility of the facility, once in orbit, to further meet these objectives. The later concepts provide a point-of-departure for the add-on study efforts.

5.1 DEMONSTRATION/TEST OBJECTIVES MET ON INITIAL DEPLOYMENT

The OCDA structure will be built-up out of a basic building block structure divided between aluminum and composites. This feature meets 35% of the demonstration objectives in the field of large structures. Figure 5-1 lists some of these objectives. An option to use either space fabricated or deployable members, or both, exists. Over 100 joining operations are required providing an opportunity to demonstrate many joining opetions. Several candidate structural approaches showing promise for future systems could be embodied into the program.

The technologies of man/machine interactions are addressed with use of the rotating boom and manipulator. A first cut at productivity potential of man and machine in a space environment will also be provided. The challenge of attitude control, and structural alignment in a varying thermal environment will be addressed during construction of the OCDA.

The installation of secondary structure and subsystem mounting for solar arrays and high voltage power distribution systems will be addressed during assembly of the OCDA itself.

Several key technologies can be explored in the large solar array area as shown in Figure 5-2. The deployment and reaction of a large area array can be demonstrated. The issues of interfacing the "ganged" array to the structure and power distribution system will be addressed. The array has tentatively been configured to operate at 200 volts but could be configured to generate high voltages of 20 kv to evaluate switching and protection problems.

Even at 200 volts, the selection of the bus system approach, and the routing and support bracket design involves many similar issues associated with the future large scale Solar Power Station. Construction operations and handling of the system with man's involvement should provide insight on developing the needed safety procedures.

Many of the basic construction operations issues associated with future construction bases will be addressed during OCDA assembly. The difficulty of resupply and storage, site logistics, site communications, power and signal routing, lighting, and safety will be solved because of the OCDA endeavor.

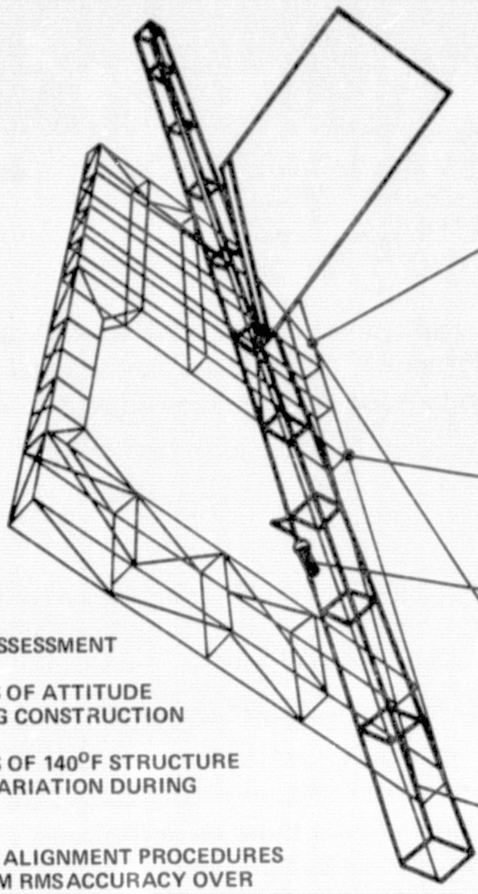


Figure 5-1 Large Structures Objectives Met on Initial Deployment

Valuable data on productivity in a space environment will be collected as well as data on the capabilities of man and machinery performance in the construction of an integrated spacecraft. Because the OCDA will eventually be used as a platform for other construction experiments, the problems associated with the mounting of construction equipment will be addressed and solved in a timely fashion.

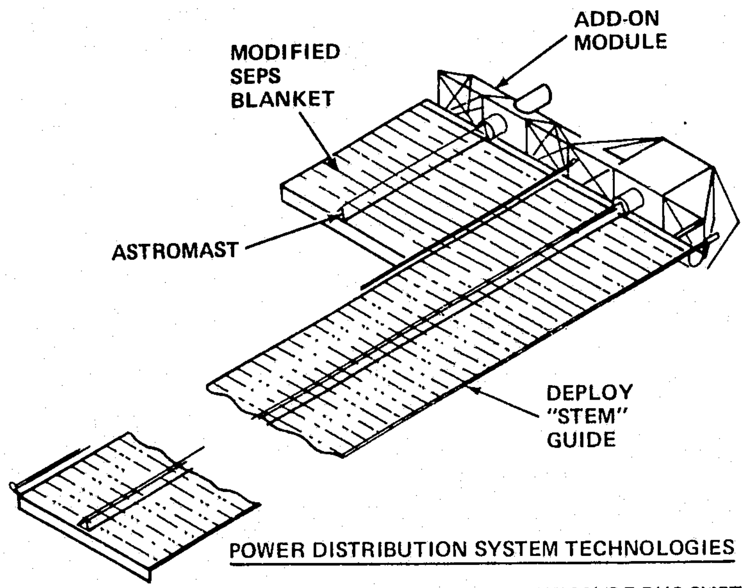
Figure 5-3 summarizes the issues addressed in the areas of propulsion and stabilization and control. The installation of propulsion units including tankage and feed lines will be covered. Resupply of propellants to maintain attitude control and stationkeeping will be an integral part of the program.

The control of large flexible structure that varies in dimensions and inertia typifies the conditions expected at the ultimate, future construction base. The installation and operation of a modest size rotary joint will provide insight to the ultimate SPS design.

In all, 40% of the demonstration objectives listed in Figure 2-3 can be met during the initial placement of the OCDA. The remainder of the objectives can be met with judicious selection of follow-on experiments that use the OCDA as a technology advancement facility.

5.2 CONTINUED UTILITY POTENTIAL

One objective of Task 5 Figure 1-2, was to establish concepts for follow-on utility of the OCDA by defining a family of experiments which demonstrate construction techniques not adequately covered during initial deployment. These efforts will be expanded during a five-month add-on study, which will provide technical definition of these experiments and identify the impact these experiments have on the



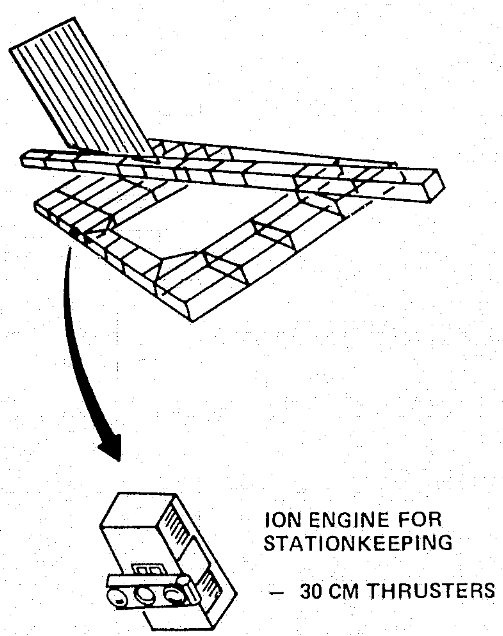
LARGE SOLAR ARRAY TECHNOLOGIES

- DEMONSTRATES ONE METHOD TO DEPLOY LARGE AREAS OF SOLAR BLANKET.
- DEMONSTRATES BLANKET INTERFACE WITH STRUCTURE, POWER BUS AND MONITOR/COMMAND SYSTEMS
- ADDRESSES ISSUES OF C/O AND FAULT ISOLATION
- COULD BE CONFIGURED TO OPERATE AT 20KV TO ADDRESS HI VOLTAGE ISSUES
- ADDRESSES THERMAL CYCLING ISSUES

POWER DISTRIBUTION SYSTEM TECHNOLOGIES

- DEMONSTRATES INSTALLATION OF BUS SYSTEM INCLUDING CONDUCTORS, POWER CONDITIONERS AND SWITCH GEAR
- ADDRESSES ISSUES OF ENERGY STORAGE FOR ATTITUDE CONTROL, SYSTEM HEATING, ETC.
- ADDRESSES ISSUES OF LARGE ROTARY JOINT INSTALLATION AND OPERATION
- ADDRESSES ISSUES OF C/O, FAULT ISOLATION & REPAIR

Figure 5-2 Solar Array & Power Distribution System Objectives Met on Initial Deployment



PROPULSION TECHNOLOGIES

- DEMONSTRATES ON ORBIT INSTALLATION OF LOW THRUST PROPULSION SYSTEMS FOR ORBIT KEEPING & ATTITUDE CONTROL
- ADDRESSES ISSUES OF PROPELLANT RESUPPLY
- ADDRESSES ISSUES OF EXHAUST CONTAMINATION OF SOLAR ARRAY

STABILIZATION & CONTROL

- ADDRESSES ISSUE OF CONTROL OF LARGE FLEXIBLE STRUCTURE
  - LOCATION OF SENSORS & ACTUATORS
- ADDRESSES CONTROL ISSUES OF CONFIGURATIONS WITH CHANGING GEOMETRY DURING CONSTRUCTION & DURING OPERATIONS
- ADDRESSES DESIGN ISSUES OF ROTARY JOINT CONTROL & ACCURACY

Figure 5-3 Propulsion & Stabilization Objectives Met on Initial Deployment

basic OCDA design, orbiter interfaces and funding requirements. By incorporating the requirements into the design, the OCDA will be facility capable of demonstrating the techniques needed for the ambitious endeavors envisioned for the future.

Follow-on experiments have been categorized into three basic themes which address the technology requirements of the five future missions identified during Task 1. These themes are:

- Theme 1 - SPS Development
  - 1a - Photovoltaic Array
  - 1b - Solar Thermal
  - 1c - Transmitting Antenna
- Theme 2 - Large Antenna Development
  - 2a - Communications
  - 2b - Radiometry
- Theme 3 - Night Illumination

Figure 5-4 shows a Theme 1 concept for mass producing a large 20-m deep beam using space fabricated members. This beam is typical of a structural element for the ultimate SPS. Six fabrication modules and additional manipulators are the equipments needed over and above the basic OCDA inventory. Three fabrication modules form the cap members and three form the battens. Three manipulators, located at the cap-to-batten joint, are used in the fastening operation.

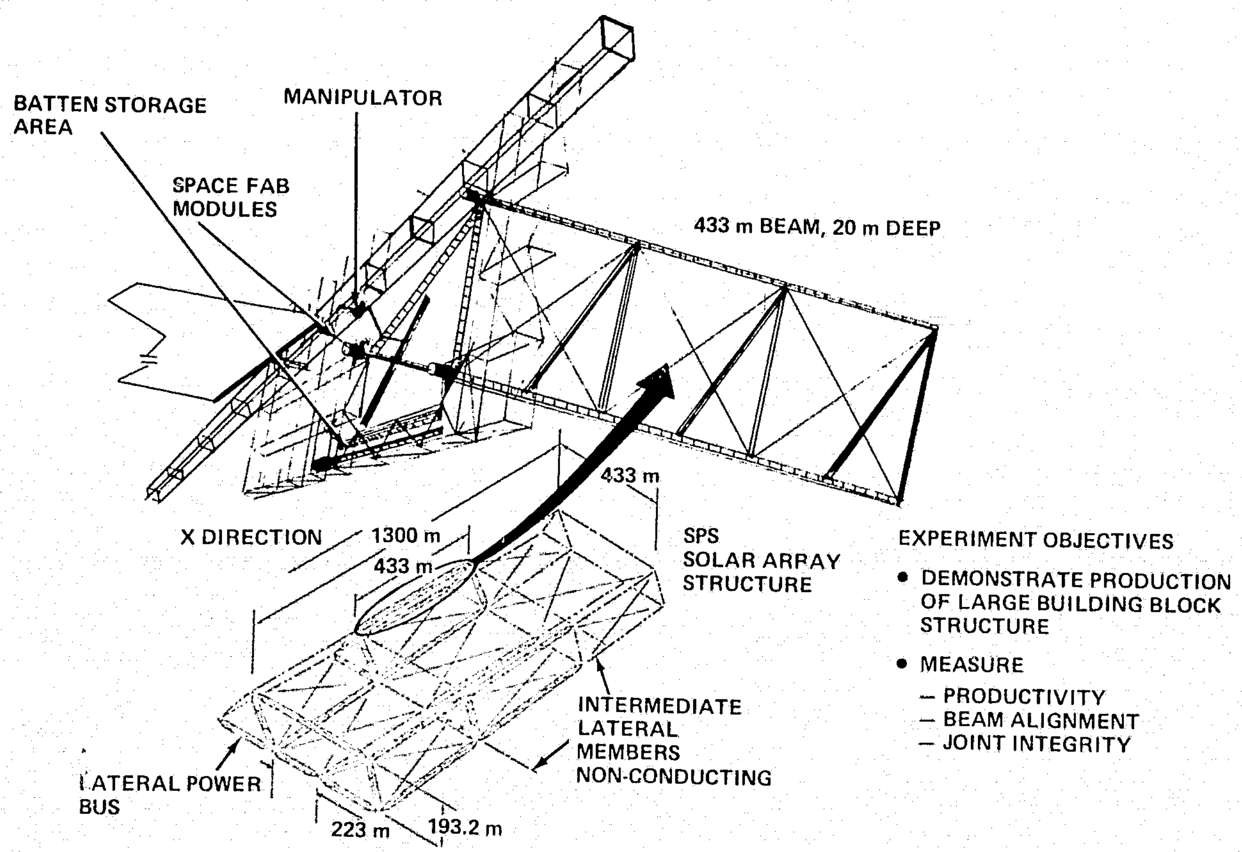


Figure 5-4 Typical Element Testing Phase Experiment

Figure 5-5 is a preliminary listing of equipments, and the weight and power requirements for a 20 m beam made in aluminum and composites. Two production rates are shown, 1 ft/min and 10 ft/min. The power requirements at the higher rate for composites is the basis for sizing the OCDA solar array and energy storage system. The add-on study effort will delineate these requirements by investigating the need for lighting, local crew stations and other construction support equipments.

ELEMENT	NO.	MASS EST ALUM, LB	MASS EST GR/COMP LB	POWER EST, W ALUM PROD RATE 1 FT/MIN	POWER EST, W ALUM PROD RATE 10 FT/MIN	POWER EST, W GR/COMP PROD RATE 1 FT/MIN	POWER EST, W GR/COMP PROD RATE 10 FT/MIN
1. IM FAB MODULE	6	44,400	33,000	2,400 (AVG)	24,000 (AVG)	7,380 (AVG)	73,800 (AVG)
2. FRAME ASSY	1	1,527	1,527				
3. WORK STATION CREW MODULE (MANIP)	3	6,000	6,000	6,480 (AVG)	6,480 (AVG)	6,480 (AVG)	6,480 (AVG)
4. PLATFORM	3	300	300				
5. RAILS	3	270	270				
6. SCAFFOLD	1	400	400				
7. CARRIAGE	3	300	300	1,500 (PK)	1,500 (PK)	1,500 (PK)	1,500 (PK)
8. SWING ARM	6	330	330	10,800 (PK)	10,800 (PK)	10,800 (PK)	10,800 (PK)
9. ALIGN. FIXTURE	3	180	180				
10. PRECISION TOOL	3	20	20	TBD	TBD	TBD	TBD
11. CABLE RIGGER	3	100	100	TBD	TBD	TBD	TBD
APPROX TOTAL		53,827	42,427	21,180	42,780	26,160	92,580

Figure 5-5 20 m Beam Fabrication Module Characteristics

Mass production of the power bus system for the ultimate SPS presents unique construction issues associated with handling large diameter thin wall tubes and forming leak-proof joints. Figure 5-6 shows a concept for simulating this construction operation using OCDA. Six 1-m diameter power bus fabrication modules and equipments for forming and interfacing the dielectric support structure are mounted to the OCDA platform. Construction is performed through the "hole" which acts as a fixture for the construction equipments.

At some point in the development of SPS, a pilot plant for proving out the integrated system would be needed. Figure 5-7 is a concept for producing a small 500 kw photovoltaic power source and associated 15 x 9 m transmitting antenna using the OCDA as a construction base. Figure 5-8 is a similar OCDA construction base layout for a solar thermal SPS pilot plant. The objective of the add-on study is to determine if these relatively complex consturction experiments can be performed at the OCDA when only supported by a Shuttle which is perhaps extended in capability to its design goal of 30 days mission duration.

The follow-on OCDA requirements for addressing microwave transmission technologies could look like the concepts shown in Figures 5-9 and 5-10. Figure 5-9 is a concept for testing a Raytheon recommended linear waveguide. This set-up simulates the power density profile of the ultimate MPTS and would provide needed information on the phase control function in a space environment. The linear array is mounted to the rotating boom on a contour control device to assure proper mechanical alignment. As shown in Figure 5-10, beam fabrication modules are mounted on a fixture along the edge of the OCDA platform to simulate mass production of the MPTS rectangular antenna. A section in the middle of the platform is used to support fixtures and machinery for the final assembly and checkout of the waveguide/rf converter subarray.

Figure 5-11 shows a concept for a flexible test bed for comparing various communications antenna designs. The platform "hole" is used as a support for interchangine rf mesh in a space fed (or lens) antenna arrangement. Various approaches for such an antenna have been identified. Each approach has a unique antenna layout. The platform provides a means of demonstrating construction of these flat surfaces in space and testing the performance of the device. Support arms from the platform to the focal point of the antenna plus the available OCDA power makes the facility a flexible test bed for collecting data on various communications or radar electronics packages.

The preliminary investigation of the continued utility potential of the OCDA shows a great deal of promise in terms of meeting a broad range of construction demonstration requirements. The add-on study efforts will delineate these potentials and provide a planning schedule that will integrate the Shuttle sortie mission activities with OCDA program objectives.

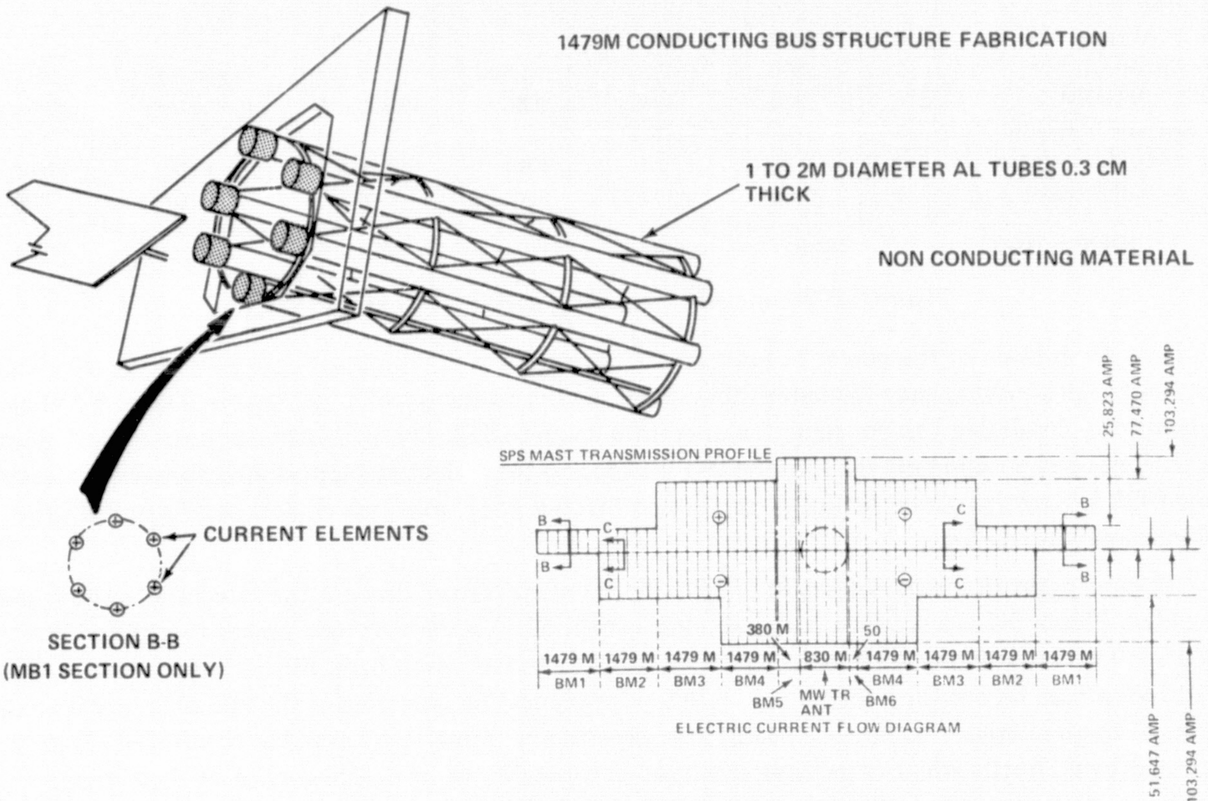
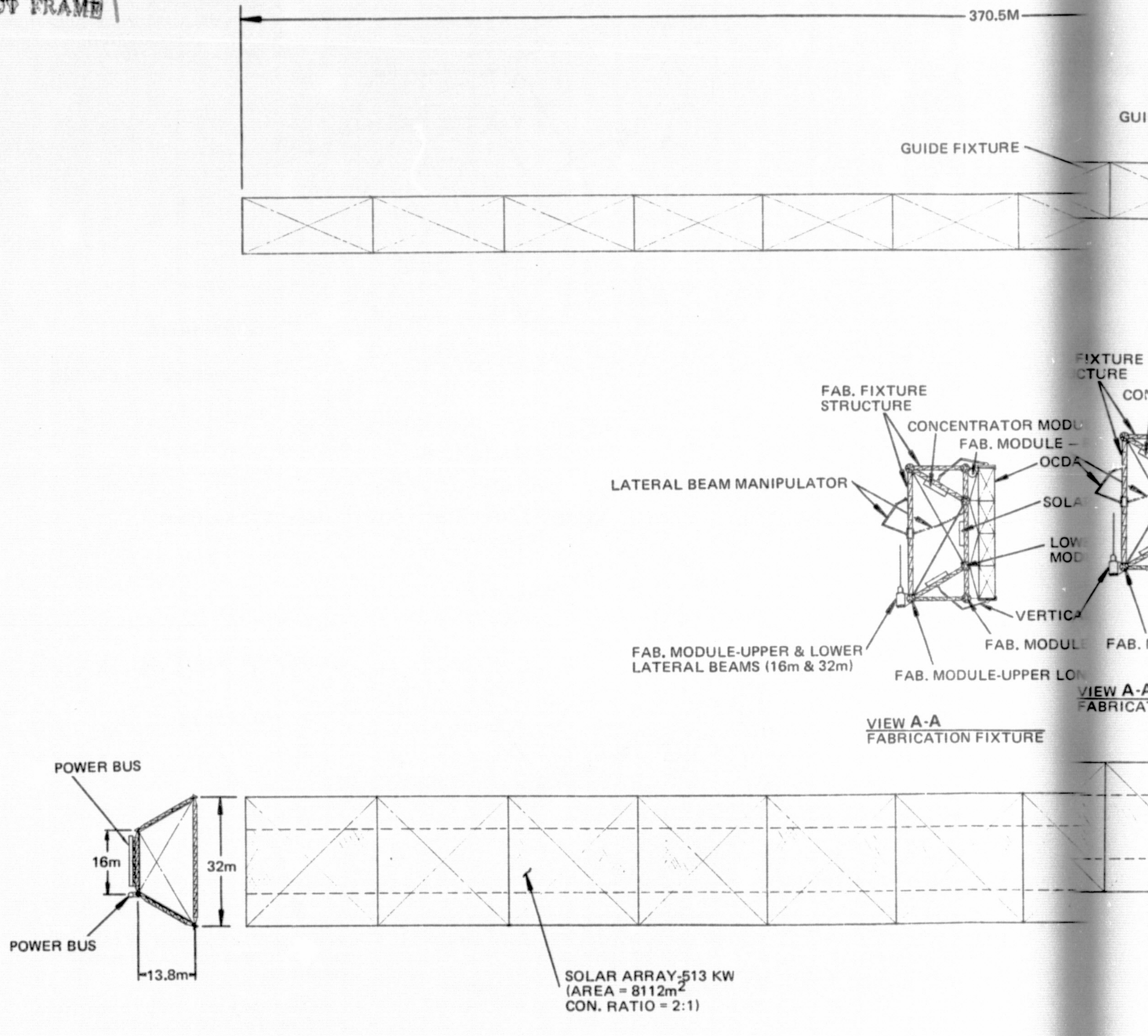


Figure 5-6 Typical Element Testing Phase Experiment

FOLDOUT FRAME



FOLDOUT FRAME 2

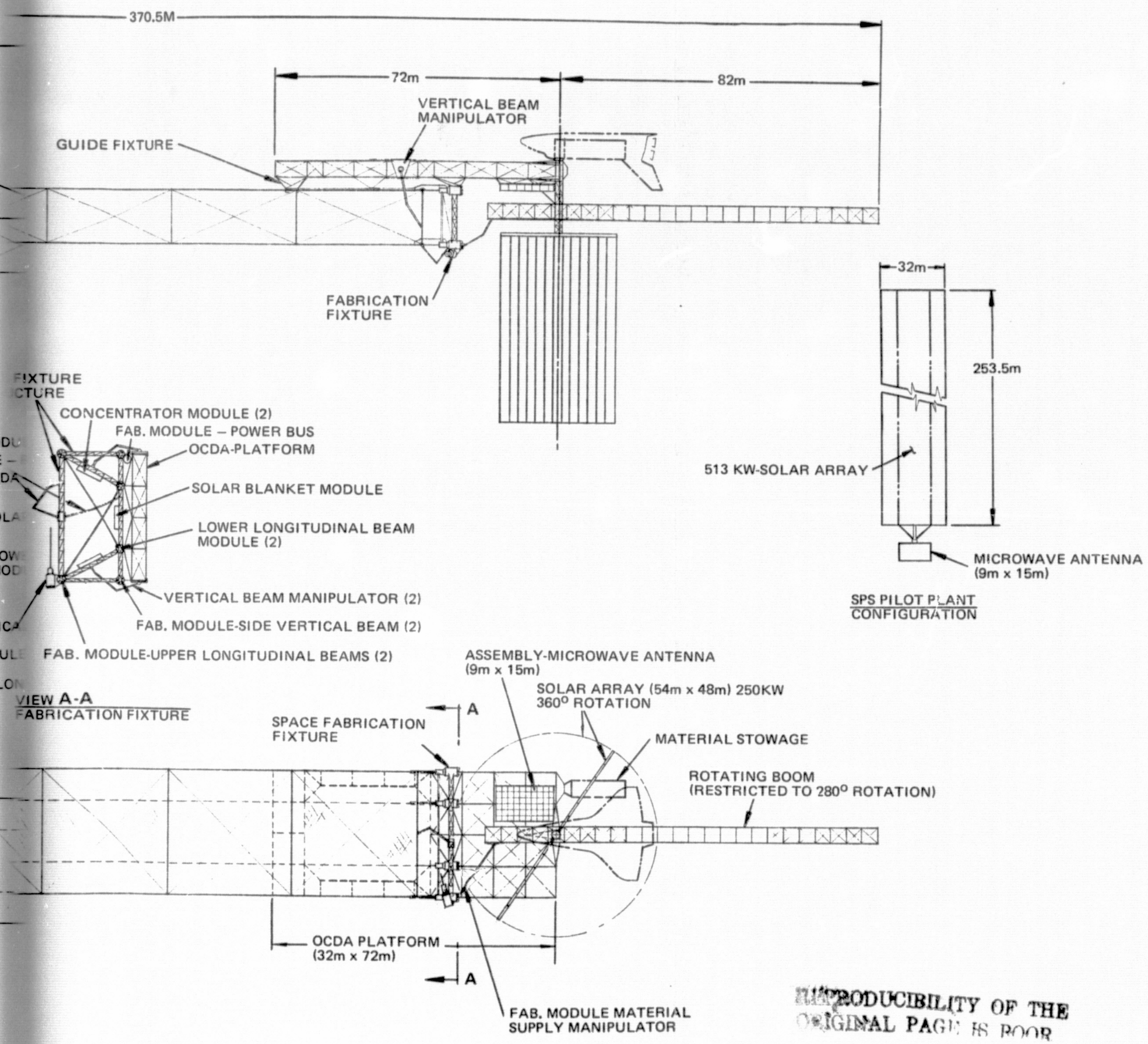


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Figure 5-7 SPS Pilot Plant OCDA Space Experiment Fabrication

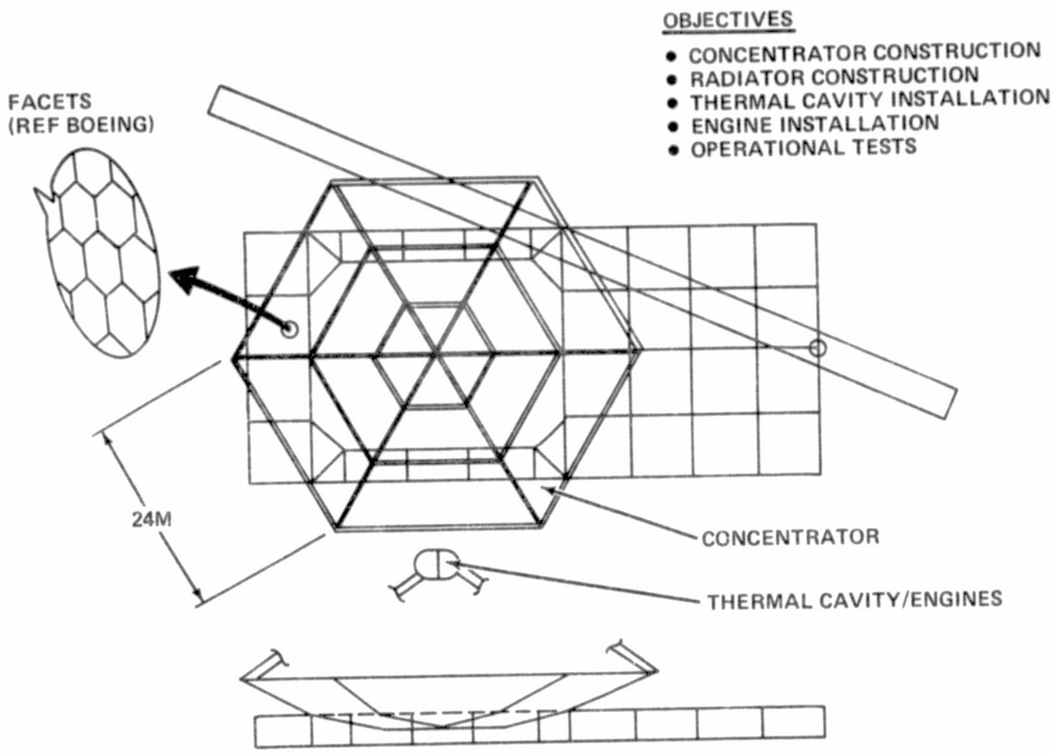
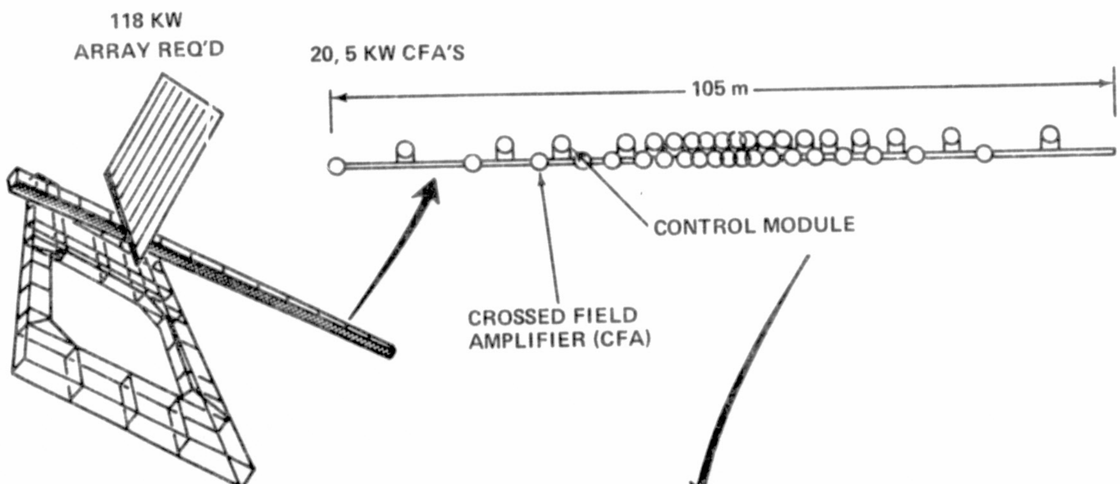


Figure 5-8 Solar Thermal Technology, 513 kw Plant



OBJECTIVES

- PRODUCE POWER TAPERED SINGLE AXIS LINEAR ARRAY
- DEMONSTRATE/TEST EQUIPMENT PERFORMANCE & PHASE CONTROL
- 20 WAVEGUIDE SECTIONS TO SIMULATE ULTIMATE MPTS 10db TAPER POWER DENSITIES
- LINEAR ARRAY MOUNTED TO ROTATING BOOM WITH ACTIVE MECHANICAL CONTOUR CONTROL DEVICES

REQ'MT SOURCE: SPACE STATION SYSTEMS ANALYSIS STUDY (NAS 8-31993)

Figure 5-9 Microwave Experiment Linear Array

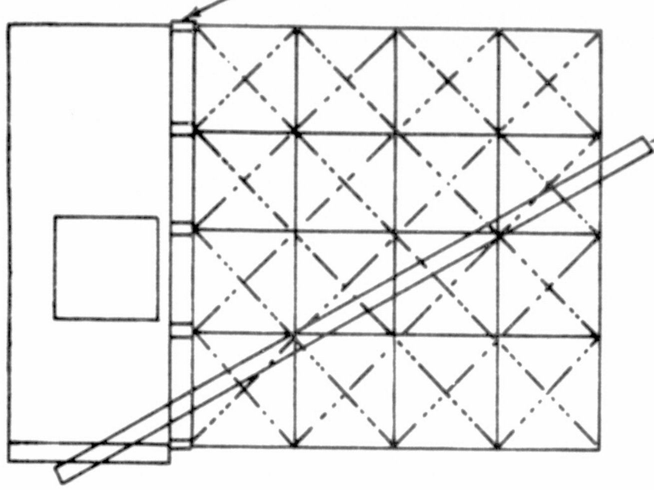
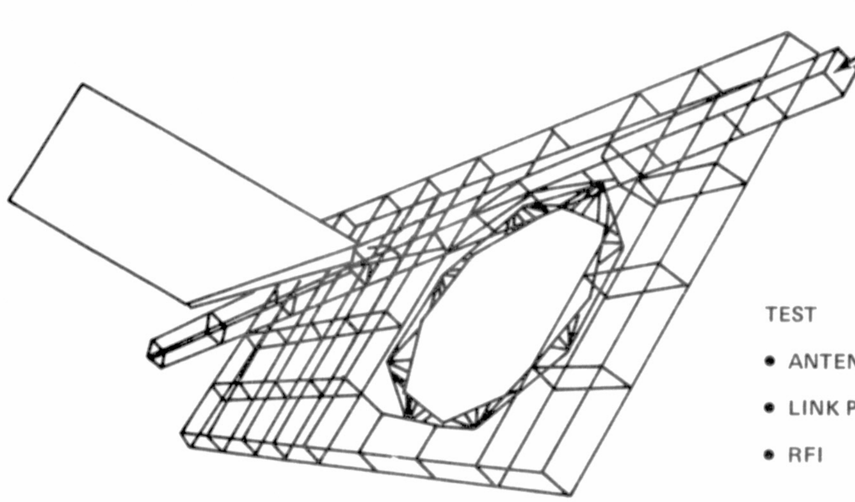


Figure 5-10 Typical Mass Production Phase Mission,
Space Fabrication MPTS



TEST

- ANTENNA PATTERNS
- LINK PERFORMANCE
- RFI

COMMUNICATIONS

- TEST BED FOR MICROWAVE (11 TO 30 GHZ) MULTI CHANNEL COMMUNICATIONS ELECTRONICS
- ASSEMBLY PROCEDURES FOR INSTALLING ANTENNA APERTURE.
  - REFLECTORS
  - PASSIVE LENSES
  - ACTIVE PHASED ARRAY

Figure 5-11 Typical Element Testing Phase Experiment

Section 6

PROGRAM COST & SCHEDULE

An overall planning schedule for design and development of the OCDA is presented in Figure 6-1. The initial orbital placement starts early in 1984. A design and development phase (C/D) runs for 3½ years with a Phase A study planned for start in 1977.

A three month period has been allocated for the OCDA construction. Construction of the OCDA itself was judged to meet 40% of the demonstration objectives. A 1½ year period (1984 & 1986) following initial placement was allocated for "Element Testing" of construction structural technologies. During this period the OCDA is used as a facility to test structural fabrication, control systems installation, etc. on a relatively small scale, but requiring more than one Shuttle flight.

Subsequent and more ambitious tasks would be introduced at a later date such as utilization of the OCDA as a construction base for space fabrication of large solar arrays and antennas.

A supplementary schedule, presented in Figure 6-2, identified recommended SR&T programs and the approximate phasing of each. Most of these programs begin the last quarter of 1977 (Fiscal 1978) and continue into the early part of Phase C/D. An exception is system level studies which start in January 1977. Technology studies of manipulator systems and EVA begin in mid-1979.

Cost estimates for the OCDA program cover Phase C/D only and assume prior initiation of a comprehensive SR&T effort. Costs of the SR&T items have not been estimated at this time.

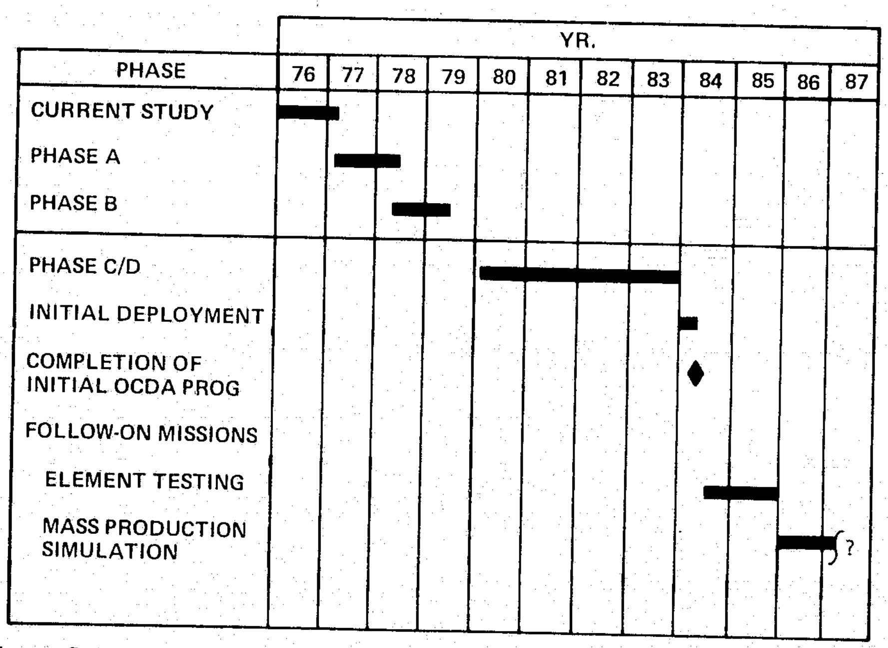


Figure 6-1 Orbital Construction Demonstration Article Planning Schedule

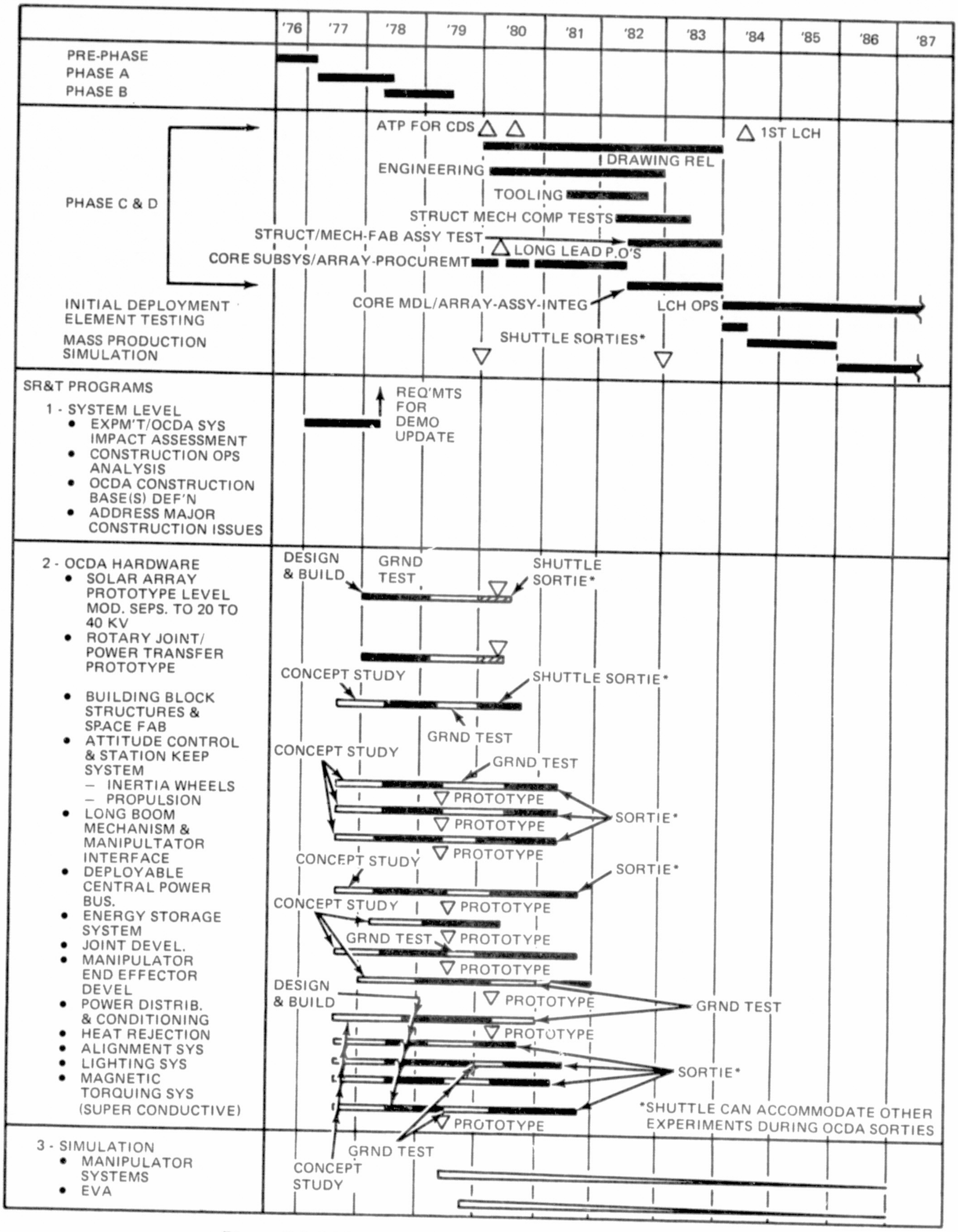


Figure 6-2 OCDA Supporting Technology Requirements

Due to the uncertainties that prevail at this stage of OCDA definition we have estimated a "high-low" range of costs. We anticipate fluctuations in this band of estimated cost as design concepts and program plans are firmed up during subsequent phases of study effort and a narrowing of the band as we approach Phase C/D due to SR&T efforts. We have used applicable and valid data from cost history, budgetary quates, and in-house analyses with appropriate qualifications, and have documented the results. Space transportation costs per flight and solar blanket cost factors were furnished by NASA.

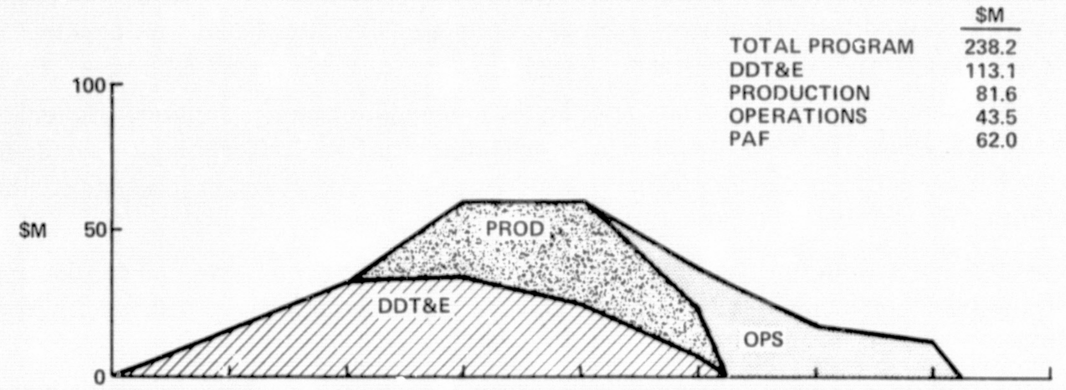
The variation in high-low estimates and the recommendations for technology studies are indicative of cost/risk areas. The areas of greatest risk are targets for SR&T efforts, which should in most cases improve the accuracy of cost estimates, and also produce design and programmatic alternatives to minimize risks and costs.

Cost projections and funding are based on the schedule discussed above, the configuration as defined in this report and detailed definition groundrules and assumptions given in the 8th Monthly Progress Note.

Summary costs are presented by major hardware element in Figure 6-3. Projected funding requirements including STS costs and a nominal allowance for spares are presented in Figures 6-4 and 6-5. Both estimates exclude orbital assembly equipment and operations as well as flight operations. A single unit of flight hardware is costed with "normal" spares. Long lead or other items critical to schedule performance, and normally available as backup by cannibalizing a second or subsequent unit, should be identified, scheduled, and costed in future studies to afford schedule protection.

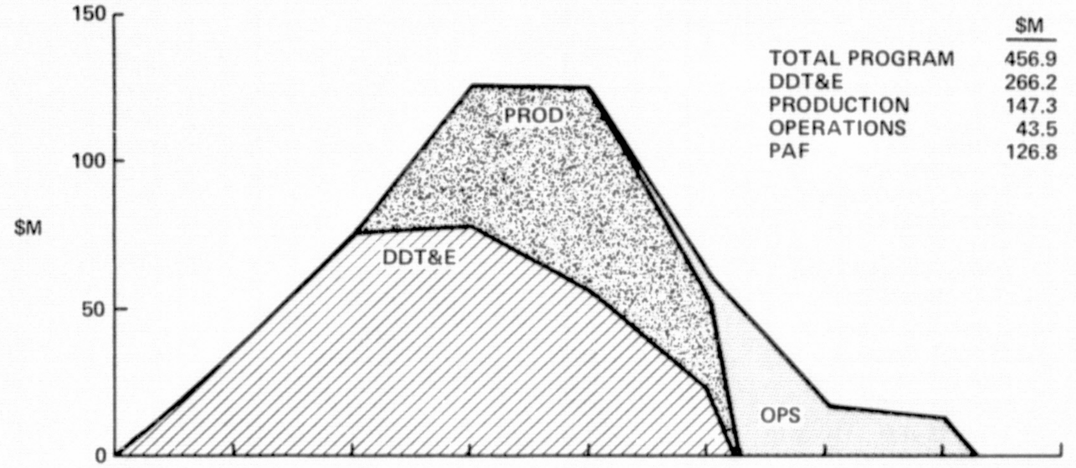
	HIGH, \$/M		LOW, \$/M	
	DDT&E	1ST UNIT	DDT&E	1ST UNIT
CORE MODULE/MAST	(\$22.5M)	(\$26.9M)	(\$11.8M)	(\$18.3M)
• STRUCTURE	4.9	1.2	2.1	0.6
• DOCKING RING	0	2.3	0	1.1
• COMM/DATA HDL	1.1	3.6	0.55	1.8
• ELECTRICAL POWER	11.9	12.4	6.8	11.1
• ACS	4.6	7.4	2.3	3.7
PLATFORM	(80.3)	(32.4)	(33.7)	(16.7)
• STRUCT/MECH	55.2	13.4	23.2	6.2
• POWER DISTRIBUTION	12.3	6.1	4.1	4.1
• PROPULSION	6.1	1.7	3.1	0.8
• ACS	6.7	6.7	3.3	3.3
• COMM ANT (WB COMM)	0	0.03	0	0.03
• DOCK RINGS (2)	0	4.5	0	2.3
ROTATING BOOM/MANIP	(75.8)	(30.9)	(30.0)	(16.7)
• STRUCT/MECH	36.7	8.9	15.4	4.1
• PWR DISTRIBUTION	20.6	10.4	6.9	6.9
• MANIP/CARRIAGE	0	5.3	0	2.6
• TRAVELLER	6.9	1.2	2.8	0.6
• ROTARY JOINT	11.6	5.1	4.9	2.5
SOLAR ARRAY	(21.3)	(27.2)	(9.7)	(13.1)
• STRUCT/MECH	1.1	6.1	.5	2.0
• SOLAR BLTKS/DEPL MECH	11.8	18.2	5.9	9.1
• PWR DISTRIBUTION	8.4	2.9	3.3	2.0
TOTAL SUBSYSTEMS	(199.9)	(117.4)	(85.2)	(64.8)
PROGRAM MANAGEMENT	24.2	12.8	10.3	7.1
SYSTEM ENGR & INTEGRATION	22.0	11.7	9.4	6.5
GSE	20.0	0	8.2	0
	(266.1)	(141.9)	(113.1)	(78.4)
TOTAL	(408.0)		(191.5)	

Figure 6-3 OCDA Cost Estimate (Excluding Flight Support, Shuttle Flights, Orbital Assembly



	1979	1980	1981	1982	1983	1984	1985	1986	1987
DDT&E	0	15.0	32.2	33.1	23.7	9.0	0	0	0
PROD	0	0.	0.	27.1	38.3	16.2	0	0	0
OPS	0	0	0	0	0	12.4	18.2	13.0	0
TOTAL	0	15.0	32.2	60.2	62.0	37.6	18.2	13.0	0

Figure 6-4 OCDA – Low Estimate



	1979	1980	1981	1982	1983	1984	1985	1986	1987
DDT&E	0	35.4	75.8	77.9	55.8	21.3	0	0	0
PROD	0	0	0	48.9	69.1	29.3	0	0	0
OPS	0	0	0	0	0	12.4	18.2	13.0	0
TOTAL	0	35.4	75.8	126.8	124.9	63.0	18.2	13.0	0

Figure 6-5 OCDA – High Estimate

Both high and low estimates assume use of standard spacecraft modules for housekeeping functions of the core system to avoid new development costs. The use of Shuttle-developed docking module and manipulator and use of a rotary joint developed for the early Space Station concepts are also assumed. "High-low" cost variations for these program elements result from uncertainty as to initial unit cost and the degree of modification which may be required. Low estimates for these and other program estimates assume minimum data, controls, management, and reporting.

One result of cost studies has been the preparation of cost sensitivity analyses which relate solar array size and platform size to cost. A graph showing sensitivity for both high and low ranges of cost is presented in Figure 6-6. Sensitivity is shown for a platform with and without the rotating manipulator boom. The steeper slope of the high estimate curves is caused by the relatively high cost per unit of blanket area. Conversely the low estimate is relatively insensitive to changes in solar array power because of the lower cost per unit factor used in preparing the low estimate.

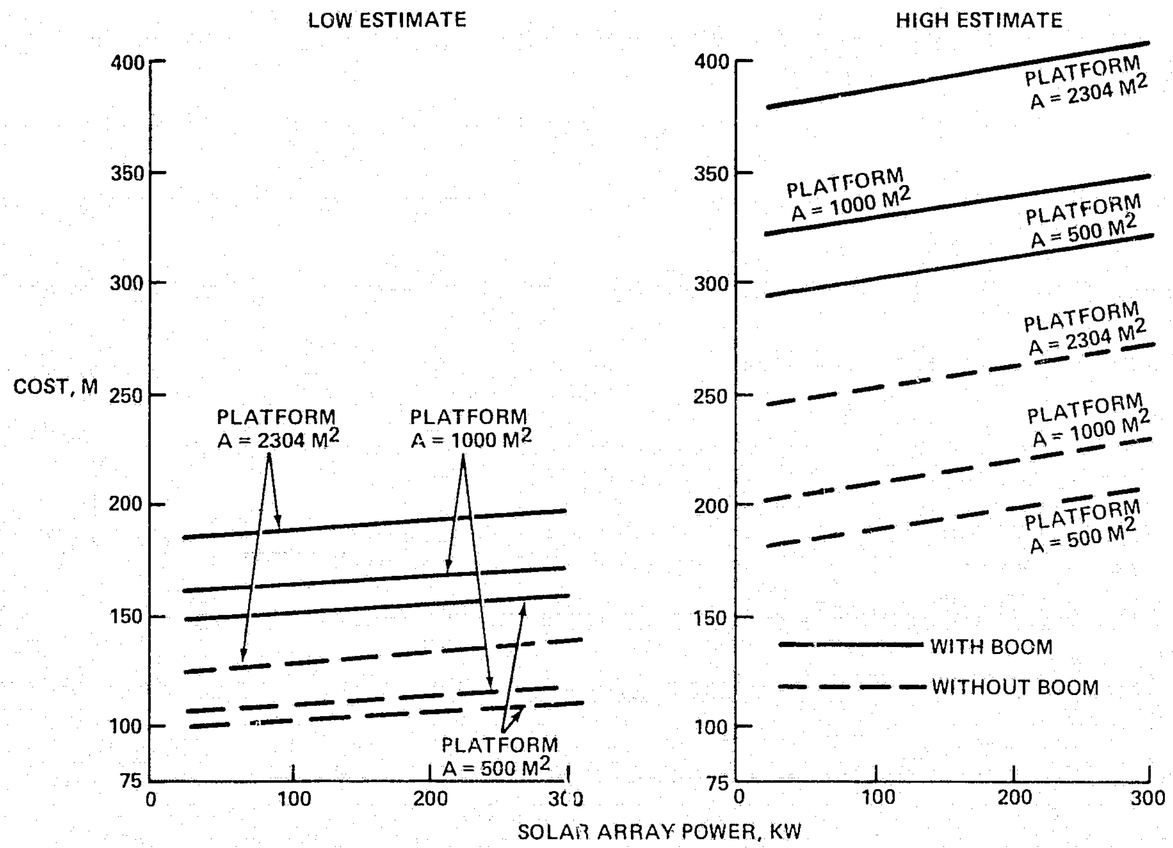


Figure 6-6 Cost Sensitivity

Section 7

CONCLUSIONS & RECOMMENDATIONS

The objective of this study was to map out an orbit demonstration program that addresses the construction issues apparent in the design of future large structures. Five future concepts were identified that embodied the requirements and issues for almost all future endeavors. Demonstration and test objectives were formulated and used as the basis for the design of a general purpose construction base that is operated from the Shuttle. This facility, the Orbit Construction Demonstration Article (OCDA), has the potential to help solve many of the technology problems involved with the construction of ultra-large structures in space.

This study estimates that the assembly of the OCDA itself in three Shuttle flights would meet 29 of the 72 objectives identified. The remainder of the objectives can be met through a series of experiments that utilize the OCDA features of abundant power, rotating boom with manipulators and a work platform to demonstrate and test the complex space fabrication construction techniques needed for economic relization of beneficial programs such as space-based solar power generation.

The OCDA program has been estimated to cost $450 million up to completion of the facility. The cost of follow-on experiments is yet to be established and will be the subject of an add-on effort to this contract.

Several program options exist and should be studied. A series of Shuttle sortie missions are being formulated that will address large structures technology. The possibility exists for utilizing the elements of demonstration articles left in-orbit by these sortie missions as parts of the OCDA's structure. A typical example is the boom for the rotating manipulator crane on the OCDA. The boom could be a product of a previous sortie mission that is testing the operation of an automated beam fabrication module.

The interrelationship of the ODCA function as an extension of the Shuttle and an association with ultimate permanent manned facility should be explored. The Shuttle with extended orbit life time afforded by the OCDA can provide the crew support needed for limited construction experiments. A permanent facility will be cost effective at some level of experiment complexity. The add-on study to this contract will address this issue of cross-over from Shuttle supported experiments to a manned facility support.

This study has shown the utility and benefit of a small general purpose construction and structures technology facility in orbit. It is recommended that the OCDA be considered as a viable program option in NASA's planning for advancing large space structures technology by:

- Initiating precursor definition studies (Phases A & B) in time for a 1979 new program start decision
- Plan for a 1984 IOC to benefit from OCDA technology advancements needed to make key descisions in the 1987 time frame on ultra large initiatives like the Solar Power Satellite.